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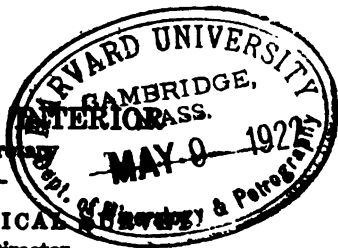


DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director



Bulletin 726

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1921

PART II.—MINERAL FUELS

DAVID WHITE AND M. R. CAMPBELL

GEOLOGISTS IN CHARGE



WASHINGTON

GOVERNMENT PRINTING OFFICE

1922

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CONTENTS.

(The letters in parentheses preceding the titles are those used to designate the papers for advance publication.)

	Page.
(A) The New Salem lignite field, Morton County, N. Dak., by E. T. Hancock (published May 6, 1921)-----	1
(B) Geology of the Cement oil field, Caddo County, Okla., by Frank Reeves (published August 10, 1921)-----	41
(C) Oil prospects in Washington County, Utah, by Harvey Bassler and J. B. Reeside, jr. (published August 15, 1921)-----	87
(D) Lignite in the Fort Berthold Indian Reservation, N. Dak., by C. M. Bauer and F. A. Herald (published December 3, 1921)-----	100
(E) Geologic structure of parts of New Mexico, by N. H. Darton (published March 31, 1922)-----	173
(F) Geologic structure and oil and gas prospects of a part of Jefferson County, Okla., by H. M. Robinson (published December 20, 1921)-----	277
(G) The Lacasa area, Ranger district, north-central Texas, by C. S. Ross (published December 23, 1921)-----	303
Index-----	315

ILLUSTRATIONS.

	Page.
PLATE I. A, Level upland in vicinity of New Salem, N. Dak.; B, Valley of Heart River in T. 138 N., R. 83 W., N. Dak.-----	6
II. A, Large glacial boulders on upland in sec. 17, T. 138 N., R. 84 W., N. Dak.; B, Cannonball marine member of Lance formation in bluff of Heart River, sec. 10, T. 138 N., R. 83 W., N. Dak.-----	7
III. Sections showing thickness, positions, and names of lignite beds in New Salem field, Morton County, N. Dak.-----	14
IV. A, Dakota Products Co.'s mine near New Salem, N. Dak.; B, Crown Butte, on upland in sec. 31, T. 140 N., R. 82 W., N. Dak.-----	28
V. Geologic map of the New Salem lignite field, Morton County, N. Dak.-----	38
VI. Geologic map of Oklahoma showing oil and gas fields-----	42
VII. Erosion features of Cyril gypsum and Whitehorse sandstone--	48
VIII. Erosion features of Cyril gypsum and Whitehorse sandstone--	49
IX. Cross-bedding in Whitehorse sandstone-----	60

	Page.
PLATE X. Plotted logs of 11 wells in Cement oil field, Caddo County, Okla.....	72
XI. Structural map of Cement oil field and surrounding territory, Caddo County, Okla.....	In pocket.
XII. Structural map of Kiowa area, Caddo County, Okla.....	In pocket.
XIII. A, "Breaks" of the Little Missouri, looking southeast toward the mouth of Hans Creek, N. Dak.; B, A thick bed of lignite in the Fort Berthold Indian Reservation, N. Dak.....	112
XIV. A, Badlands in sec. 26, T. 147 N., R. 93 W., N. Dak.; B, Badlands in sec. 25, T. 147 N., R. 93 W., N. Dak.....	113
XV. A, Missouri River, N. Dak., as seen from the upper margin of the badlands, looking north; B, Valley of Moccasin Creek near its mouth, in sec. 6, T. 147 N., R. 92 W., N. Dak.....	114
XVI. Stratigraphic sections in Fort Berthold Indian Reservation, N. Dak., showing correlation of coal beds.....	123
XVII. Sections of lignite beds in the northern part of the Fort Berthold Indian Reservation, N. Dak.....	132
XVIII. A, Bare buttes of the Fort Union formation on the south side of Hans Creek, N. Dak.; B, Log concretions in Fort Union formation.....	140
XIX. A, Glacial boulders on the upland in T. 147 N., R. 93 W., N. Dak.; B, Bed of lignite 8 feet thick in natural exposure in sec. 14, T. 147 N., R. 93 W., N. Dak.....	141
XX. Sections of lignite beds in the northern part of the Fort Berthold Indian Reservation, N. Dak.....	144
XXI. A, Fossil log standing nearly upright in clay shale of the Fort Union formation; B, Fossil stump in Fort Union formation.....	152
XXII. A, Sage-brush flat of Hans Creek, N. Dak., and bluffs of the Fort Union formation; B, Rolling upland in the Fort Berthold Indian Reservation, N. Dak.....	153
XXIII. Sections of lignite beds in the southwestern part of the Fort Berthold Indian Reservation, N. Dak.....	154
XXIV. A, Buttes in sec. 9, T. 148 N., R. 93 W., N. Dak.; B, Buttes in T. 148 N., R. 93 W., N. Dak.....	160
XXV. A, View up Squaw Creek, N. Dak.; B, Bare buttes in Squaw Creek valley in sec. 10, T. 148 N., R. 93 W., N. Dak.....	161
XXVI. Sections of lignite in the southern part of the Fort Berthold Indian Reservation, N. Dak.....	172
XXVII. Map of the northern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds.....	In pocket.
XXVIII. Map of the southwestern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds.....	In pocket.
XXIX. Map of the southern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds.....	In pocket.
XXX. Map of New Mexico.....	17
XXXI. A, Bliss sandstone, San Andres Mountains, N. Mex.; B, Coyote Butte, N. Mex.....	18
XXXII. A, Bluewater Canyon, N. Mex.; B, Inscription Rock, N. Mex.....	18
XXXIII. A, Wingate sandstone at Rito, N. Mex.; B, Sandstone of Glorieta Mesa, near La Cuesta, N. Mex.....	18

	Page.
PLATE XXXIV. Sandstones at Navajo Church, N. Mex.-----	189
XXXV. A, Navajo and Dakota sandstones at Atarque, N. Mex. ; B, Dakota sandstone at Bluewater Falls, N. Mex.-----	196
XXXVI. A, Dome near San Ignacio, N. Mex. ; B, West front of Sacramento Mountains, N. Mex.-----	197
XXXVII. West front of Sandia Mountains at Bernalillo, N. Mex.---	218
XXXVIII. Geologic map of Sandia and Manzano mountains and Sierra de los Pinos, N. Mex.-----	218
XXXIX. A, Dakota sandstone on west slope of Cerrillos Basin, N. Mex. ; B, West front of Chupadera Mesa, N. Mex.---	220
XL. Geologic map of Tularosa Basin, N. Mex.-----	224
XLI. Pilot Knob on west slope of San Andres Mountains, N. Mex.-----	228
XLII. Geologic map of Jornada del Muerto, N. Mex.-----	230
XLIII. Geologic map of part of Socorro County, N. Mex.-----	234
XLIV. A, Base of Magdalena group east of Socorro, N. Mex. ; B, Upturned Magdalena beds east-northeast of So- corro, N. Mex.-----	236
XLV. A, Mesa del Yeso, N. Mex. ; B, Sierrita Mesa, Naci- miento uplift, N. Mex.-----	237
XLVI. A, Pyramid Rock, N. Mex. ; B, Uplift at Atarque, N. Mex.-----	254
XLVII. A, West slope of Zuni uplift at Nutria, N. Mex. ; B, Northwest slope of Zuni uplift east of Gallup, N. Mex.-----	255
XLVIII. Geologic map of parts of Valencia and Socorro counties, N. Mex.-----	262
XLIX. Sections across Sierra Lucero in Valencia and Socorro counties, N. Mex.-----	264
L. Map showing structure of valleys of Rio Salado and Alamosa Creek, Socorro County, N. Mex.-----	266
LI. Index map of Oklahoma-----	278
LII. Map showing the geologic structure in a part of Jeffer- son County, Okla.-----	284
LIII. Map showing geologic structure in Lacasa area, Tex.---	308
LIV. Selected well records in Lacasa area, Tex.-----	314
FIGURE 1. Index map of North Dakota showing location of New Salem lignite field-----	2
2. Structure section through New Salem and Sims, N. Dak.-----	11
3. Sections showing position of lignite beds in Fort Union forma- tion in New Salem lignite field, N. Dak.-----	18
4. Graph showing the heating value of North Dakota lignite as compared with other coals with which it may have to com- pete-----	22
5. Generalized section of Permian "Red Beds" of Oklahoma.-----	46
6. Rocks exposed in Cement oil field, Caddo County, Okla.-----	47
7. Approximate boundary between marine and nonmarine sedi- ments of basal Permian and upper Pennsylvanian in Kansas, Oklahoma, and Texas.-----	59
8. Map showing absence of relation of ridges to structure and other features in Cement oil field, Caddo County, Okla.-----	70

	Page.
FIGURE 9. Map of parts of Washington County, Utah, and Mohave County, Ariz -----	88
10. Map of the oil field near Virgin City, Utah-----	94
11. Map of part of the Virgin anticline, Washington County, Utah, showing the Harrisburg and Washington domes-----	100
12. Map of the Bloomington dome, Washington County, Utah-----	103
13. Index map showing location of Fort Berthold Indian Reservation, N. Dak-----	110
14. Diagram showing heating value of North Dakota lignite, compared with that of certain subbituminous and bituminous coals-----	123
15. Sections of lignite bed C, Fort Berthold Indian Reservation, N. Dak., showing characteristics of the bed and of partings--	126
16. Map showing the major structure of northeastern New Mexico--	189
17. Section across Colfax and Union counties, N. Mex-----	190
18. Section from Pederal Mountain across Guadalupe and Quay counties, N. Mex-----	195
19. Map of Esterito dome, Guadalupe County, N. Mex-----	196
20. Section from south end of Rocky Mountains to Cuervo Butte, Guadalupe County, N. Mex-----	197
21. Generalized sections across the Rocky Mountains in New Mexico--	201
22. Sections across the plateaus of southeastern Santa Fe County, southwestern San Miguel County, and eastern Torrance County, N. Mex-----	202
23. Sections across the Sacramento Cuesta and Guadalupe Mountains, N. Mex-----	208
24. Sketch section of anticlines and fault between Alamogordo and High Rolls, N. Mex-----	209
25. Map showing relation of anticline in Tijeras coal field, N. Mex--	218
26. Sections across the Sanida and Manzano mountains and the Sierra de los Pinos, N. Mex-----	219
27. Sections across Chupadera Mesa, N. Mex-----	222
28. Sections across Tularosa Basin, N. Mex-----	225
29. Log of deep boring at Oscuro, N. Mex-----	228
30. Logs of two railroad wells at Carrizozo, N. Mex-----	228
31. Sections across the Jornada del Muerto, N. Mex-----	230
32. Sections across eastern Socorro County, N. Mex-----	235
33. Sketch section across the Joyita Hills, Socorro County, N. Mex--	240
34. Sections across San Pedro Mountain and Nacimiento Range, N. Mex-----	242
35. Map showing structure in part of Rio Arriba County, N. Mex--	243
36. Section across the plateau in Rio Arriba County, N. Mex-----	245
37. Section along San Juan River, San Juan County, N. Mex-----	246
38. Geologic sketch map of part of McKinley County, N. Mex-----	248
39. Map showing structure of part of northwestern New Mexico--	255
40. Sections across the Zuni Mountain uplift, N. Mex-----	256
41. Sections across the Gallup-Zuni Basin, N. Mex-----	258
42. Section across north-central Socorro County, N. Mex-----	267
43. Section from Mimbres Mountains eastward through Kingston and Hillsboro, N. Mex-----	269
44. Sections across the Florida Mountains, Luna County, N. Mex--	271

	Page.
FIGURE 45. Section through the Snake Hills, southwest of Deming, Luna County, N. Mex.-----	272
46. Section through the Klondike Hills, Luna County, N. Mex.-----	273
47. Section across the Victorio Mountains, south of Gage, Luna County, N. Mex.-----	273
48. Sketch section across the north end of the Big Hatchet Mountains, Hidalgo County, N. Mex.-----	274
49. Diagram showing principal sandstone and conglomerate beds that were found serviceable in mapping the structure of a part of Jefferson County, Okla.-----	281
50. Key map of north-central Texas showing location of Lacasa area -----	308
51. Columnar section of rocks exposed in Lacasa area, Tex.-----	305
52. Key map of Lacasa area, Tex., showing locations of wells whose logs are given in Plate LIV.-----	312

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1921.

PART II. MINERAL FUELS.

DAVID WHITE and M. R. CAMPBELL, *Geologists in charge.*

INTRODUCTION.

The Survey's "Contributions to economic geology" have been published annually since 1902. In 1906 the increase in the number of papers coming under this classification made it necessary to divide the contributions into two parts, one including papers on metals and nonmetals except fuels and the other including papers on mineral fuels. In 1915 the year included in the title was changed from the year in which the field work reported in these papers was done to the year of publication, and in consequence there was no volume entitled "Contributions to economic geology, 1914." The subjoined table gives a summary of these bulletins.

United States Geological Survey "Contributions to economic geology."

Date in title.	Date of publication. ^a	Bulletin No.	Date in title.	Date of publication. ^a	Bulletin No.
1902.....	1903	213	1913, Part I.....	1915	580
1903.....	1904	225	Part II.....	1915	581
1904.....	1905	250	1914, Part I.....	1916	620
1905.....	1906	285	Part II.....	1916	621
1906, Part I.....	1907	315	1916, Part I.....	1917	640
Part II.....	1907	316	Part II.....	1917	641
1907, Part I.....	1908	340	1917, Part I.....	1918	660
Part II.....	1908	341	Part II.....	1918	661
1908, Part I.....	1909	380	1918, Part I.....	1919	690
Part II.....	1910	381	Part II.....	1919	691
1909, Part I.....	1911	430	1919, Part I.....	1920	710
Part II.....	1911	431	Part II.....	1920	711
1910, Part I.....	1912	470	1920, Part I.....	1921	715
Part II.....	1912	471	Part II.....	1921	716
1911, Part I.....	1913	530	1921, Part I.....	1922	725
Part II.....	1913	531	Part II.....	1922	726
1912, Part I.....	1914	540			
Part II.....	1914	541			

^a The date given is that of the complete volume; beginning with Bulletin 285, the papers have been issued as advance chapters as soon as they were ready.

As a subtitle indicates, most of the papers in these volumes are of three classes—(1) short papers describing as thoroughly as conditions will permit areas or deposits on which no other report is

likely to be prepared; (2) brief notes on mining districts or economic deposits whose examination has been merely incidental to other work; and (3) preliminary reports on economic investigations the results of which are to be published later in more detailed form.

Although these papers set forth mainly the practical results of economic investigations they include brief theoretical discussions and summary statements of conclusions if these appear to require prompt publication.

MAY 11 1921

DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

BULLETIN 726—A

THE NEW SALEM LIGNITE FIELD
MORTON COUNTY, NORTH DAKOTA

BY

EUGENE T. HANCOCK

Contributions to economic geology, 1921, Part II

(Pages 1-39)

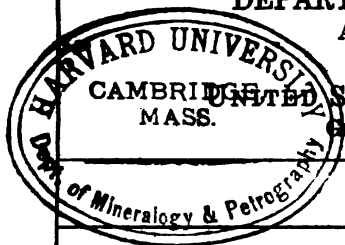
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WASHINGTON

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1921



DEPARTMENT OF THE INTERIOR

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1921**

CONTENTS.

	Page.
Introduction.....	1
Field work	3
Previous publications.....	3
Geography.....	4
Commercial relations.....	4
Surface features	5
Geology	5
Stratigraphy.....	5
General character of the rocks.....	5
Tertiary (?) system.....	7
Lance formation	7
Lower part of the Lance formation.....	7
Cannonball marine member.....	7
Tertiary system.....	10
Fort Union formation.....	10
Structure.....	11
Lignite.....	12
Origin and distribution.....	12
Physical properties	14
Chemical properties	15
Comparative heating value	21
Mining	23
Description by townships.....	25
T. 137 N., R. 82 W.....	25
T. 138 N., R. 82 W.....	25
T. 139 N., R. 82 W.....	26
T. 140 N., R. 82 W.....	26
T. 137 N., R. 83 W.....	27
T. 138 N., R. 83 W.....	28
T. 139 N., R. 83 W.....	28
T. 140 N., R. 83 W.....	29
T. 137 N., R. 84 W.....	29
T. 138 N., R. 84 W.....	30
T. 139 N., R. 84 W.....	30
T. 140 N., R. 84 W.....	31
T. 137 N., R. 85 W.....	32
T. 138 N., R. 85 W.....	33
T. 139 N., R. 85 W.....	34
T. 137 N., R. 86 W.....	36
T. 138 N., R. 86 W.....	37

ILLUSTRATIONS.

	Page.
PLATE I. <i>A</i> , Level upland in vicinity of New Salem, N. Dak.; <i>B</i> , Valley of Heart River in T. 138 N., R. 83 W., N. Dak.-----	6
II. <i>A</i> , Large glacial boulders on upland in sec. 17, T. 138 N., R. 84 W., N. Dak.; <i>B</i> , Cannonball marine member of Lance formation in bluff of Heart River, sec. 10, T. 138 N., R. 83 W., N. Dak.-----	7
III. Sections showing thickness, positions, and names of lignite beds in New Salem field, Morton County, N. Dak.-----	14
IV. <i>A</i> , Dakota Products Co.'s mine near New Salem, N. Dak.; <i>B</i> , Crown Butte, on upland in sec. 31, T. 140 N., R. 82 W., N. Dak.-----	26
V. Geologic map of the New Salem lignite field, Morton County, N. Dak.-----	38
FIGURE 1. Index map of North Dakota showing location of New Salem lignite field.-----	2
2. Structure section through New Salem and Sims, N. Dak.-----	11
3. Sections showing position of lignite beds in Fort Union formation in New Salem lignite field, N. Dak.-----	13
4. Graph showing the heating value of North Dakota lignite as compared with other coals with which it may have to compete.-----	22

THE NEW SALEM LIGNITE FIELD, MORTON COUNTY, NORTH DAKOTA.

By **EUGENE T. HANCOCK.**

INTRODUCTION.

The lignite of North Dakota is a fuel of so low a grade, at least by comparison with the better coals of the Rocky Mountain region and the East, that it has attracted little attention, but with the difficulties of transportation that have been experienced in this country in recent years it becomes more and more important for localities that have undeveloped resources of even a poor quality to exploit them sufficiently to know their quantity and quality, so that when the need comes for utilizing the domestic supply it can be done intelligently and without needless waste. In order to accumulate information regarding such undeveloped resources of mineral fuel, the United States Geological Survey has been for a number of years making detailed examinations of many coal fields. Much of this work has been done primarily for the purpose of gathering data for the separation of the land into mineral and nonmineral classes as prescribed by the old coal-land law, but the Survey has also had in mind the need for information by the general public regarding the fuel resources of the country, and this need has been met by the publication of a number of papers describing certain coal fields. The present paper is one of this character.

The New Salem lignite field lies within the great lignite region of western North Dakota, northwestern South Dakota, and eastern Montana, on its southeastern margin. Some of these border fields contain less lignite than those lying in the interior portion of the region, for the reason that as the rocks lie in a great basin dipping slightly toward the center from all directions, the upper formations, which carry the larger lignite beds, are present in the interior and the lower formations, which carry thinner and more irregular beds, are found on the margin of the basin. In the New Salem field both groups of formations are present, and hence this field contains some thick beds and some thin ones.

As this field is on the southeastern margin of the greater region of lignite-bearing beds, it follows that in the areas lying farther to the

east and southeast the rocks are lower in the geologic scale and hence lie entirely below the lignite-bearing formations, and therefore it is useless to search for lignite in those areas.

Before 1912 the southeastern margin of the lignite field of North Dakota was known in a general way, but no exact information regarding it had ever been published. In 1912 E. R. Lloyd, of the United States Geological Survey, began the work of delimiting the field on its southeast side, and this work was continued during the summer of 1913. The region examined by Lloyd embraces an area

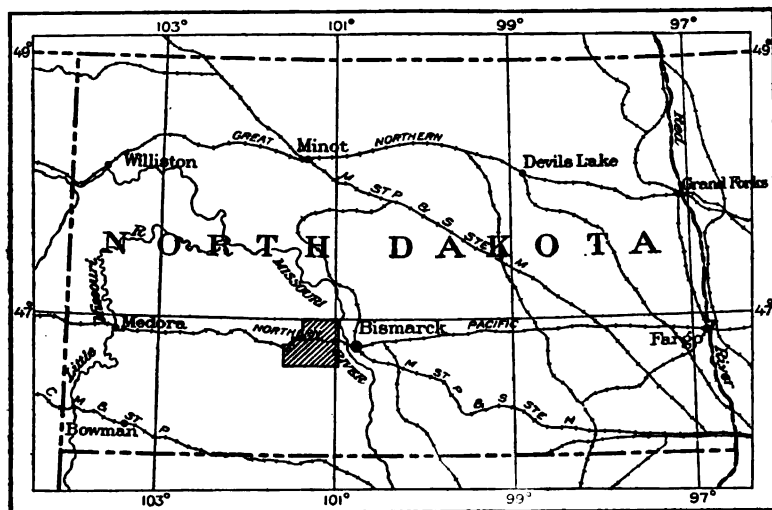


FIGURE 1.—Index map of North Dakota showing location of New Salem lignite field.

extending from the State line northeastward to the ninth standard parallel. It has an average width of about 4 miles and in general is bounded on the south and east by Cannonball River. Throughout this part of the field lignite was found to occur only locally and in thin beds. During the autumn of 1914 the geologic mapping was continued by the writer north of the ninth standard parallel throughout an area of about 600 square miles, in the west-central part of which is situated the prosperous town of New Salem. This area includes Tps. 137 to 140, Rs. 82 to 86, except 3½ townships in the northwest corner. Owing to the prominence of this town as a shipping point for a large agricultural community and as a center for the distribution of lignite¹ to the surrounding country, it is considered appropriate to refer to this area as the New Salem lignite field. The area surveyed in 1914 and included under this name is shown in figure 1.

¹ Since this report was prepared the mine at New Salem has been abandoned.

FIELD WORK.

The field examination upon which this report is based was made in August, September, and October, 1914, by Raymond C. Moore, Delbert Williams, Sidney Swanker, Frank Bunn, and the writer. The work was done under the direct supervision of M. R. Campbell, to whom the writer is indebted for many valuable suggestions. Information was contributed by many of the residents of the field; and as it is impracticable to make individual mention of these courtesies, acknowledgments can be made only in this general way.

The geologic examination was made primarily with a view of classifying the land and of determining the amount of lignite which it contains. An attempt was made to ascertain the extent and thickness of the different lignite beds from a study of their outcrops, supplemented by such data as could be obtained concerning lignite encountered in sinking wells. The mapping was done with the plane table, telescopic alidade, and stadia rod. By their use the outcrop of each lignite bed was accurately mapped wherever the bed is exposed, but where it is concealed by the overburden, as it is almost invariably, the outcrop was determined upon the basis of known elevations combined with a knowledge of the structure of the bed.

The township plats of the General Land Office were used as base maps for the field work and for the construction of Plate V. Most of the land corners are not difficult to find, as they are on well-established fence lines or in the public highways, many of which are laid out on the section lines. The original locations of the corners are generally marked by mounds and pits, covered with unusually dense prairie grass.

The land net, on a scale of 2 inches to the mile, was transferred to the plane-table field sheet directly from the township plats. With the exception of the stadia traverse of the outcrops of the lignite beds, all locations incident to the geologic mapping were made by triangulation. The mapping was controlled horizontally by land corners, together with conspicuous surface features carefully tied into section or township corners. Vertically the mapping was controlled by elevations taken directly from the Northern Pacific Railway profile, and the elevations were carried north and south by means of vertical angles.

PREVIOUS PUBLICATIONS.

That portion of southwestern North Dakota including Cannonball River and its tributaries has long been known to be a part of the great lignite region of the Dakotas and eastern Montana. The presence of what was supposed to be "stone coal" (lignite) was recognized in the vicinity of Mandan during the explorations by Lewis

and Clark in 1804-1806. They first noted lignite on the left bank of the Missouri about 20 miles above the mouth of Cannonball River.² Nearly every succeeding expedition added something of interest, but it was not until the explorations of the geologist F. V. Hayden, under the direction of Lieut. G. K. Warren, that any attempt was made to prepare and publish a geologic map of the region.³

In 1874 an expedition under the command of Gens. Custer and Ludlow, accompanied by N. H. Winchell, geologist, made a reconnaissance trip to the Black Hills, crossing the Cannonball River field on the way.⁴

The Geological Survey of North Dakota has published during recent years several articles relating to the lignite fields of the State. The region including Cannonball River and its tributaries, however, has received little attention owing to the more fully developed territory to the north and west. A. G. Leonard,⁵ State geologist, has recently described several sections exposed on Cannonball and Heart rivers in Morton County. The Cannonball member is described by Lloyd and Hares.⁶

The Cannonball River lignite field, which was examined by E. R. Lloyd⁷ in 1912 and 1913, joins and partly overlaps the lignite field described by A. G. Leonard.⁸

GEOGRAPHY.

COMMERCIAL RELATIONS.

The main line of the Northern Pacific Railway crosses the New Salem lignite field in an east-west direction near its central part. Wagon roads throughout the field follow the section lines except in the vicinity of the principal streams, where the land is so rough as to render this impracticable. The principal towns on the Northern Pacific Railway in this field are Sweetbriar, Judson, New Salem, and Almont. Owing to the complete system of public roads, one or another of these towns is readily accessible from almost every part of the field. The entire field is well settled and is supplied with adequate postal facilities.

² Lewis, Meriwether, and Clark, William, *Original Journals*, vol. 1, p. 200, New York, Dodd, Mead & Co., 1904.

³ Hayden, F. V., Notes explanatory of a map and section illustrating the geologic structure of the country bordering on the Missouri River from the mouth of the Platte River to Fort Benton: *Acad. Nat. Sci. Philadelphia Proc.*, vol. 9, pp. 109-116, 1858.

⁴ Winchell, N. H., Report of a reconnaissance of the Black Hills of Dakota made in the summer of 1874 by William Ludlow, pp. 22 et seq., 1875.

⁵ Leonard, A. G., The Cretaceous and Tertiary formations of western North Dakota and eastern Montana: *Jour. Geology*, vol. 19, pp. 507-547, 1911.

⁶ Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Lance-Laramie problem: *Jour. Geology*, vol. 23, pp. 523-547, 1915.

⁷ U. S. Geol. Survey Bull. 541, pp. 243-292, 1914.

⁸ U. S. Geol. Survey Geol. Atlas, Bismarck folio (No. 181), 1912.

SURFACE FEATURES.

The New Salem lignite field lies in the Great Plains physiographic province, and hence it is devoid of trees except a few along the streams. Nearly all the drainage from this field empties into Heart River and eventually reaches Missouri River near Mandan. Big Muddy and Sweetbriar creeks are the principal affluents of Heart River. All these streams and many of their smaller tributaries contain either running water or water in holes throughout the year.

The field as a whole exhibits three rather distinct types of surface features. The feature most characteristic of the region is the very gently rolling prairie interrupted here and there by high boulder-covered ridges and small isolated buttes. (See Pl. I, A, and Pl. IV, B.) Throughout this rolling upland the highways commonly follow the section lines, the country is rather thickly settled, and the wide expanse of prairie land is marked by numerous broad fields of wheat, oats, flax, rye, or barley.

The alluvium along the principal streams gives rise to a second type of surface not wholly unlike that described above but much less extensive. These almost flat but gently sloping valley bottoms range from a quarter of a mile to a mile in width and contain a very productive soil.

Upland areas thoroughly dissected into badlands by numerous streams extend from the alluvial flats back into the country for several miles and constitute the third type of surface features. Districts characterized by surfaces of this type are suitable principally for grazing.

GEOLOGY.

STRATIGRAPHY.

GENERAL CHARACTER OF THE ROCKS.

The Fort Union formation, which occurs in the lower part of the Tertiary system (Eocene series) and which contains most of the valuable lignite in the Dakotas and eastern Montana, lies at the surface throughout a little more than half of the New Salem lignite field. It is underlain by a group of beds which are now tentatively classified as probably of early Tertiary age and are referred to the Lance formation. The upper 250 or 300 feet of this formation is very different in character from the underlying beds, which are more typical of the Lance. The underlying portion is composed of alternating beds of shale and sandstone, which, when eroded, give rise to badlands. Fossil leaves collected near the top of the lower part of the Lance indicate that it is of fresh-water origin, and they have been identified by F. H. Knowlton as belonging to the Fort Union flora. The upper 250 to 300 feet of the formation, on the other hand,

contains the remains of a marine fauna which until recently has not been recognized in this part of the stratigraphic section. The part of the formation containing this fauna has been mapped separately and is designated the Cannonball marine member of the Lance formation. It forms the surface rock throughout most of the eastern part of the field. It is reasonably certain, although there are no rock outcrops, that lower Lance beds occur at the surface throughout the extensive flat area on Little Heart River, in the southeastern part of the field. A collection of fossil leaves obtained about 20 feet above the alluvial flat in the NE. $\frac{1}{4}$ sec. 31, T. 138 N., R. 83 W., and determined as Fort Union species by Knowlton indicates the presence of lower Lance beds on either side of Heart River as far north as that place.

The Quaternary period is represented in this field for the most part by glacial boulders and by alluvial material along the principal streams. The stratigraphy is shown by the accompanying table.

Tertiary and Quaternary formations in New Salem lignite field, N. Dak.

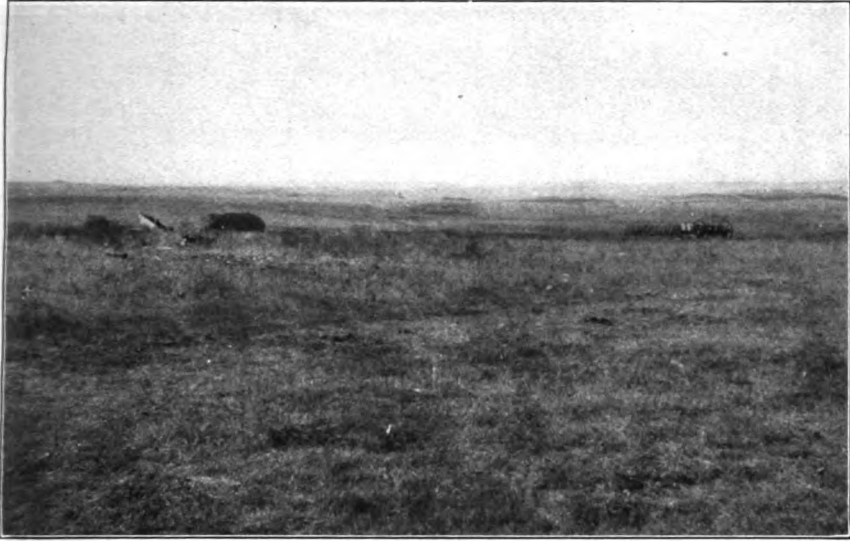
System.	Series.	Formation.	Character.	Thickness (feet).
Quaternary.			Alluvium, glacial boulders, and till.	
Erosional unconformity.				
Tertiary.	Eocene.	Fort Union formation.	Massive light-yellow sandstone, sandy and clay shale, black carbonaceous shale, and lignite.	250-350
Tertiary(?).	Eocene(?).	Lance formation.	Cannonball marine member, predominantly fine-grained, soft, unconsolidated sandstone, with alternating light-yellow and darker bands. Subordinate amount of light-yellow to dark-yellow and gray sandstone in lenticular beds.	200-300
			Undifferentiated Lance, dark shale, yellow sandstone.	400-525
Cretaceous.	Upper Cretaceous.	Fox Hills sandstone.	Not exposed.	

The New Salem lignite field is merely a northern extension of the Cannonball River lignite field. In the report on that field Lloyd⁹ describes briefly the formations exposed from the Fox Hills sandstone to the White River formation. A somewhat detailed description of the marine member of the Lance formation and its bearing on the Lance-Laramie problem appears in a recent paper by E. R. Lloyd and C. J. Hares,¹⁰ and its fauna has been described by T. W. Stanton.¹¹

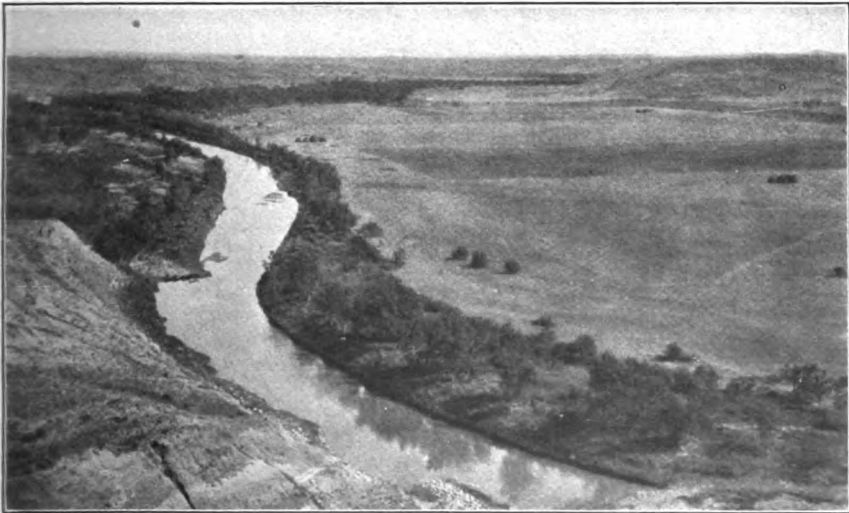
⁹ Lloyd, E. R., The Cannonball River lignite field, Morton, Adams, and Hettinger counties, N. Dak.: U. S. Geol. Survey Bull. 541, p. 243, 1914.

¹⁰ Jour. Geology, vol. 23, pp. 523-547, 1915.

¹¹ The fauna of the Cannonball marine member of the Lance formation: U. S. Geol. Survey Prof. Paper 128, pp. 1-66, 1920 (Prof. Paper 128-A).



A. LEVEL UPLAND IN THE VICINITY OF NEW SALEM, N. DAK., LOOKING EAST.

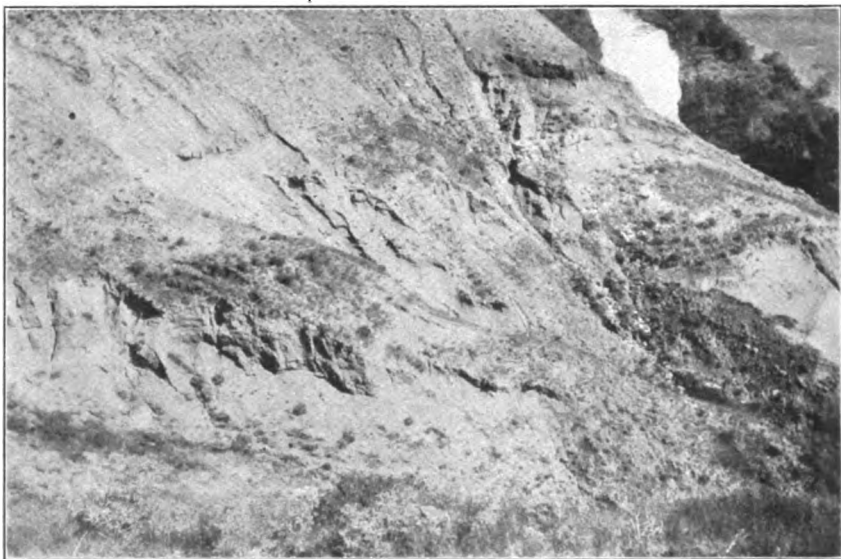


B. VALLEY OF HEART RIVER IN T. 138 N., R. 83 W., N. DAK.

Level upland in the distance.



A. LARGE GLACIAL BOULDERS ON UPLAND IN SEC. 17, T. 138 N., R. 84 W., N. DAK.



B. CANNONBALL MARINE MEMBER OF LANCE FORMATION IN BLUFF OF HEART RIVER, SEC. 10, T. 138 N., R. 83 W., N. DAK.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

Lower part of the Lance formation.—The lower beds shown in the stratigraphic section measured in secs. 25 and 36, T. 137 N., R. 84 W., are believed to represent a transition from the underlying fresh-water beds into the marine member of the Lance formation. These beds not only have a striking resemblance to the Fort Union beds, but they contain numerous fragments of silicified wood, and one silicified log fully 2 feet in diameter was observed. Aside from the above-mentioned collection of leaves, which were determined by F. H. Knowlton to be Fort Union species, no fossils were obtained in this field from the lower part of the Lance formation. Fragmentary vertebrate remains were found in this part of the Lance in the Cannonball River field, farther south,¹² abundant dinosaur and turtle bones were found in several places in the Standing Rock Indian Reservation,¹³ and a few collections of dinosaur bones have been made near the mouth of Cannonball River.¹⁴

Cannonball marine member.—The Cannonball marine member comprises the upper 200 to 300 feet of the Lance formation. It is exposed in many of the cut banks on Heart River, as shown in Plate II, B, and at numerous points on Sweetbriar Creek. Within the area described in this report it has yielded the following invertebrate fossils, identified by T. W. Stanton:

Nucula planimarginata Meek and Hayden.
Yoldia scitula Meek and Hayden.
Leda mansfieldi Stanton.
Glycimeris sublimbricata Meek and Hayden.
Trigonarca? hancocki Stanton.
Arctica ovata (Meek and Hayden).
Dentalium pauperculum Meek and Hayden.
Lunatia obliquata Hall and Meek.
Anchura perveta Stanton.
Pyrifusus (Neptunella) newberryi Meek and Hayden?
Fasciolaria? (Mesorhytis) dakotensis Stanton.
Turricula? contorta Meek and Hayden.
Ringicula dubia Stanton.
Cylichna scitula Meek and Hayden?
Lamna cuspidata Agassiz.

¹² Lloyd, E. B., and Hares, C. J., op. cit., p. 528.

¹³ Calvert, W. B., and others, *Geology of the Standing Rock and Cheyenne River Indian Reservations, North and South Dakota*: U. S. Geol. Survey Bull. 575, pp. 21-22, 1914.

¹⁴ Stanton, T. W., *Washington Acad. Sci. Proc.*, vol. 2, p. 250, 1909. Leonard, A. G., *The Cretaceous and Tertiary formations of western North Dakota and eastern Montana*: Jour. Geology, vol. 19, p. 524, 1911.

The following section includes the lower part of the Fort Union formation, the Cannonball marine member of the Lance, and the uppermost beds of the lower part of the Lance:

Section measured from the NW. $\frac{1}{4}$ sec. 36, T. 137 N., R. 84 W., to the NE. $\frac{1}{4}$ sec. 30, T. 137 N., R. 83 W.

Fort Union formation:		Ft.	in.
Sandstone, yellow, hard; forms "rim rock"-----		1	
Shale, yellow, sandy-----		3	
Shale, sandy; contains unios and gastropods-----			6
Sandstone, light yellow, mainly unconsolidated but with an occasional resistant layer-----		27	
Lignite (location 56 on accompanying map)-----		4	8
Sandstone, yellow, soft, unconsolidated; contains a few layers of darker-yellow hard sandstone-----		16	
Sandstone, yellow-----		6	
Shale, light gray-----		10	
Shale, dark bluish drab, sandy-----		11	
Shale, light gray, sandy, grading upward into almost pure white shale-----		21	
Shale, carbonaceous-----			9
Lignite, impure-----			8
Lignite-----			9
Shale, carbonaceous-----		1	
Sandstone, white, hard-----		6	
Concealed-----		5	
		114	4

Cannonball marine member of Lance formation:

Sandstone, light yellow, soft-----	3	
Sandstone, white, shaly-----	1	6
Sandstone, brown, shaly-----	1	6
Sandstone, white, coarse grained, cross-bedded-----	2	
Sandstone, soft, shaly-----	35	
Sandstone, light gray, thin bedded-----	1	
Sandstone, buff, soft, shaly-----	27	
Sandstone, light bluish gray, becoming browner near the top; contains numerous hard yellowish-brown sandstone concretions-----	32	
Sandstone, hard, forming a "rim rock"; fossiliferous; contains numerous dark-brown disklike concretions-----	2	
Sandstone, brown, shaly, soft; contains numerous thin bands of yellow very fine grained sandstone typical of Cannonball marine member-----	32	
Sandstone, yellow, hard, resistant, forming "rim rock"	1	
Sandstone, gray, with occasional yellow bands, very fine grained, texture uniform throughout-----	16	
Sandstone, hard, discontinuous; in places contains almost perfectly spherical concretions ("cannon- balls")-----	1	

	Ft.	in.
Cannonball marine member of Lance formation—Continued.		
Sandstone, soft, fine grained, made up of alternating light-yellow and dark-gray to black bands; contains a few yellowish-brown iron-stained concretions; typical of Cannonball marine member.....	26	
Sandstone, hard, forming a "rim rock"; contains numerous iron-stained concretions.....	1	6
Sandstone, yellow to buff, soft.....	2	
Sandstone, soft, fine grained; contains yellow and dark bands typical of Cannonball marine member.....	5	
Sandstone, white to light yellow, hard.....	2	
Sandstone, soft, fine grained; consists of light-yellow bands interlaminated with dark bands.....	12	
	208	6

Lower part of Lance formation:

Sandstone, very hard; in places contains numerous concretions and fragments of silicified wood; a silicified log 2 feet in diameter was observed at one exposure.....	3	
Sandstone, soft, shaly, fine grained; made up of alternating light-yellow and dark bands.....	22	
Sandstone, white; contains numerous concretions.....	2	
	27	
Total thickness.....	344	10

The following section, though less detailed than the section just given, serves to illustrate the character of the Cannonball marine member of the Lance formation in another part of the field:

Section of the Cannonball marine member of the Lance formation, containing possibly a part of the lower Lance, measured in a cut bank on the north side of Heart River in sec. 10, T. 138 N., R. 83 W.

	Feet.
Top of Cannonball marine member of Lance formation.	
1. Partly concealed, but the few exposures indicate soft gray sandy shale.....	75
2. Sandstone, brown, very hard and resistant, forming a well-defined shelf; in places very fossiliferous, containing marine shells.....	4
3. Sandstone, yellow, soft, unconsolidated.....	15
4. Sandstone, fine grained, soft, unconsolidated, consisting of yellowish-brown bands alternating with darker bands and containing lenticular masses of sandstone. The entire mass has a characteristic somber hue.....	43
5. Sandstone, similar to No. 4, but the belt is of lighter color....	45
6. Sandstone, similar to No. 4. Part of this may be lower Lance.....	115
	297

The top of the section given above marks the contact between the Cannonball marine member of the Lance formation and the overlying Fort Union formation.

These sections show that the Cannonball marine member is composed predominantly of fine-grained soft, more or less unconsolidated sandstone made up of light-yellow bands alternating with darker bands and including a subordinate amount of light to dark yellow and gray sandstone that commonly occurs in lenticular beds.

Several collections of marine invertebrate fossils were made in the Cannonball member in the New Salem field during the season of 1914, and the species have been identified by T. W. Stanton as belonging to the modified Fox Hills fauna.

TERTIARY SYSTEM.

FORT UNION FORMATION.

The Fort Union formation occurs at the surface throughout the northern and western parts of the field. The upper part of the formation as originally laid down has been removed by erosion. The maximum thickness of the remaining part is 350 feet. The formation consists mainly of massive light-yellow sandstone, sandy and clay shale, black carbonaceous shale, and lignite. The lignite beds occur throughout, but those of greatest economic importance lie above the lower 100 feet of the formation. The sandstone in the Fort Union is as a rule more resistant than that of the Cannonball marine member and gives rise to a gently rolling upland, whereas the soft unconsolidated sandstone of the underlying marine member is extensively cut by small streams, giving rise to a much more uneven surface. The relatively resistant sandstone of the Fort Union formation occurs as outliers throughout the eastern part of the field and rises above the general surface in the form of buttes.

The age of the Fort Union is attested by six collections of fossil leaves and 23 collections of invertebrates taken from different parts of the field and identified as of Fort Union age. The invertebrates, identified by T. W. Stanton, are as follows:

- Unio sp. fragments.
- Corbula mactriformis Meek and Hayden.
- Viviparus sp.
- Campeloma multiligneata (Meek and Hayden).
- Campeloma sp.
- Viviparus retusus Meek and Hayden.
- Viviparus leai Meek and Hayden.
- Goniobasis nebrascensis Meek and Hayden.
- Campeloma producta White.
- Unio priscus Meek and Hayden.
- Viviparus trochiformis Meek and Hayden.
- Thaumastus limnaeiformis Meek and Hayden.

The following fossil plants were identified by F. H. Knowlton:

Leguminosites arachnoides Lesquereux.
Platanus sp.
Sapindas sp.?
Aralia? sp.
Populus cuneata Newberry.
Populus amblyrhyncha Ward.
Glyptostrobus europaeus (Brongniart) Heer.
Taxodium occidentale Newberry.
Viburnum sp.
Platanus, probably *P. raynoldsii* Newberry.
Sequoia nordenskiöldi Heer?
 Gigantic leaf, probably *Ficus*.
Sapindus affinis Newberry.
Sapindus grandifolius? Ward.
Celastrinites? sp.

STRUCTURE.

Throughout the greater part of the field there is a slight dip of 5 to 10 feet to the mile toward the northwest. This very low northwesterly dip is modified, however, by numerous local irregularities

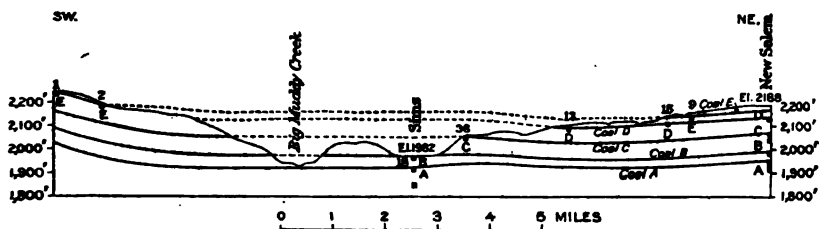


FIGURE 2.—Structure section through New Salem and Sims, N. Dak., showing the Fort Union formation. The numbers refer to corresponding numbers on the map (Pl. V).

of the strata, which become apparent only where it is possible to traverse clearly defined beds, such as beds of lignite or sandstone or fossil-bearing beds. In the course of the geologic mapping it became evident that there is a very gentle syncline (see fig. 2) whose axis trends in a northwesterly direction from the point where Big Muddy Creek crosses the south line of the field to the northeast corner of T. 138 N., R. 86 W. It is also evident from the elevations obtained on definitely traced beds that there is a region of minor uplift extending from sec. 34, T. 139 N., R. 85 W., south and east to the vicinity of the northeast corner of T. 138 N., R. 82 W. Evidence of the above-mentioned major structural features is afforded by the observed dips, some of which clearly indicate still other minor irregularities in the strata. The lignite beds in T. 137 N., Rs. 83 and 84 W., dip southwest at a rate of 5 to 8 feet to the mile. Those in T. 137 N., R. 86 W., dip very gently in the direction of Big Muddy Creek. There is, however, an appreciable northward dip of 2 to 3 feet in 100 feet at the

Ramsland mine, near the north edge of sec. 6. Again, the lignite beds mapped in secs. 4, 5, and 6, T. 138 N., R. 85 W., appear to dip southwestward at the rate of about 50 feet to the mile. In general, the beds at the old Dakota Products Co.'s mine near New Salem dip very gently toward the northwest, and a similar dip was observed in the lignite beds mapped in the north row of townships in this field.

Figure 2 represents graphically the apparent syncline noted in the lignite beds in the western part of the New Salem field. The cross section extends from New Salem through Sims into sec. 7, T. 137 N., R. 86 W. The elevations and distances between the beds have been plotted to scale. Owing to insufficiency of the data, however, it can not be stated certainly that the correlation as indicated from New Salem to Sims is correct, and it is quite possible that the bed which crops out at Sims is bed A instead of bed B. All observed dips in the coal beds place the axis of the syncline just north and east of Sims. Bed E, in the New Salem section, has probably been removed by streams or by glacial action, and glacial materials have taken its place.

LIGNITE.

ORIGIN AND DISTRIBUTION.

No lignite beds were seen in the Cannonball member of the Lance formation and only one bed in the undifferentiated portion of the Lance formation below it in the New Salem field. The valuable beds of lignite are confined to the upper 200 or 300 feet of the Fort Union formation. There are few exposures of lignite, owing to the thick mantle of soil which is almost everywhere present, and for this reason it is extremely difficult to correlate lignite beds exposed at widely separated localities.

Early in Fort Union time swamps were formed over wide areas and large quantities of vegetal matter accumulated in them. The accumulation of this organic material and its burial under water, out of contact with the atmosphere, resulted in the formation of lignite.

There are only a few places in this field where erosion has been sufficient to expose a lignite bed continuously for more than a few hundred feet. The geologist's work in mapping the beds therefore consists mainly of searching for the few isolated exposures, most of which have been made by stripping, and of correlating the beds on the basis of elevation, in conjunction with an interpretation of the structure. In certain localities, as for example in T. 137 N., R. 86 W., and in the area of Fort Union rocks in T. 137 N., R. 83 W., the individual lignite beds could be traced with little difficulty. In general, this is equivalent to saying that wherever it was possible to determine the stratigraphic position of a lignite bed from its relation to the

base of the Fort Union, reasonably accurate correlation was possible, but for the beds stratigraphically higher in the Fort Union, where the mantle of soil is deep and where a knowledge of the structure is more or less vague, the most carefully made correlations are more or less doubtful. The exposures of lignite in the New Salem field are believed to represent five beds. The term lignitic horizons, in all probability, would more nearly represent the true conditions, as the beds are known to be very lenticular. For convenience of description, however, these beds are here referred to in ascending order as beds A, B, C, D, and E. The approximate distance of each bed above the base of the Fort Union formation is as follows:

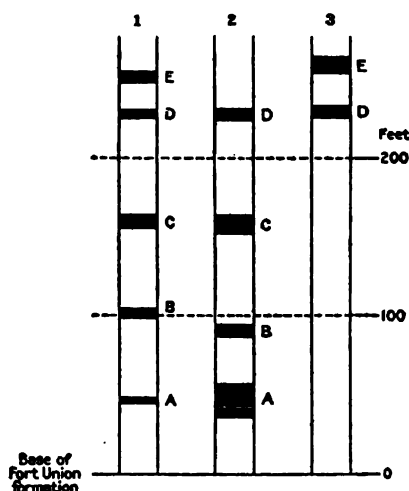


FIGURE 3.—Sections showing positions of lignite beds in Fort Union formation in New Salem lignite field, N. Dak. 1, Average section for the field; 2, section measured in air shaft of mine in sec. 7, T. 139 N., R. 85 W., $2\frac{1}{2}$ miles northwest of New Salem; 3, section in shaft and drill hole at abandoned mine of Dakota Products Co., New Salem.

A, 45 feet; B, 100 feet; C, 155 feet; D, 230 feet; E, 254 feet. Figure 3 represents graphically the distances between the various beds and shows the correlation of these beds with those exposed in a mine at New Salem and a mine $2\frac{1}{2}$ miles northwest of New Salem.

The thickness of each bed at various places is shown on Plate III, and the location of each of the sections is shown on the accompanying map (Pl. V.) Two lignite beds in the Fort Union formation were mapped in T. 137 N., R. 83 W. The lower bed (bed B) occurs about 100 feet above the base of the formation, and the upper one (bed C) about 55 feet higher. Bed B was also mapped throughout a large area west of Heart River, and a lower bed that was measured at several places in the southwest quarter of T. 138 N., R. 85 W., and in sec. 4, T. 137 N., R. 85 W., was correlated with bed B. Three

beds were mapped in T. 137 N., R. 86 W. The lowest bed is exposed only at location 43,¹⁵ in sec. 25. The next higher bed occurs at about the horizon of bed B, and the highest bed, which is well exposed in sec. 6, was correlated with bed E.

The exposures of lignite in the vicinity of Sims are thought to represent two beds. The lower bed is supposed to be bed B, and the upper one, which is about 100 feet above it, is designated bed C.

The exposures of lignite in New Salem Township and in the northern part of the township lying immediately south are thought to represent three separate beds, the lower one of which is correlated with bed C at Sims. The upper beds are 55 and 77 feet above bed C and accordingly are designated beds D and E, respectively.

In the vicinity of Judson, in the northeastern part of the field, exposures of lignite observed at several places about 50 feet above the base of the Fort Union formation are believed to represent bed A. Exposures of lignite which occur higher in the formation are correlated upon the basis of structure and elevation with beds C, D, and E. In addition to these beds in the Fort Union formation, there is a lignite bed near the top of the lower undifferentiated part of the Lance formation in which lignite is being mined at present in T. 137 N., R. 82 W. This bed is probably from 200 to 300 feet below bed A of the Fort Union formation.

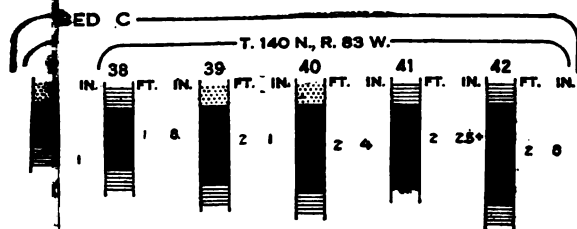
The lignite beds are considered in detail in the descriptions of individual townships.

PHYSICAL PROPERTIES.

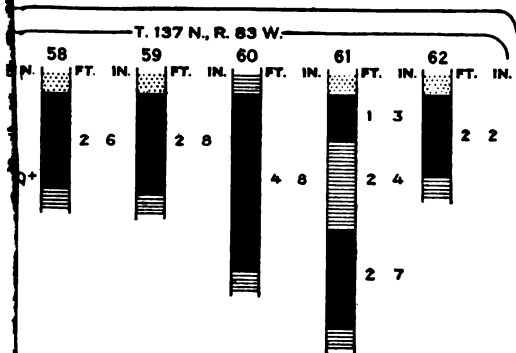
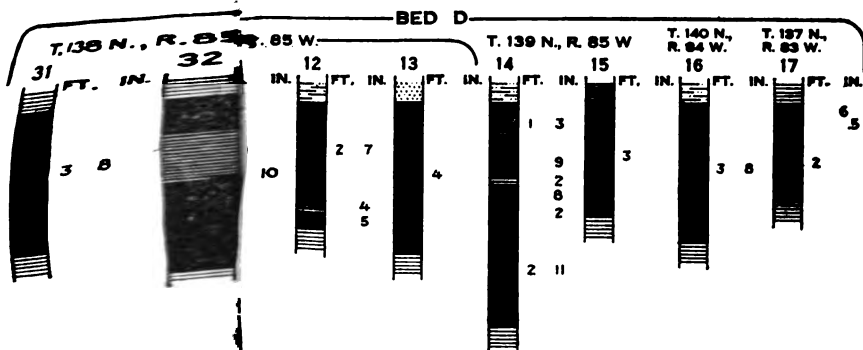
The lignite of the New Salem field is similar to that from other parts of North Dakota. Most of the unweathered lignite has a dull luster, and much of it a tough, woody texture. It is very dark brown, and the powder and streak are brown to yellow. Careful examination of the woody parts shows considerable variation in color, luster, and texture. Dark-brown lignite having a comparatively dull luster contains numerous small lenses of bright black lignite, ranging from a thin film up to layers an inch or more in thickness. In certain places the luster is dull, the woody texture is lacking, and the lignite contains a large percentage of noncombustible material or ash.

When fresh lignite, which usually contains about 40 per cent of moisture, is exposed to the air it loses a considerable percentage of this moisture, shrinks, and soon breaks up into small pieces of irregular form. This tendency of lignite to fall to pieces on exposure is a serious handicap to the development of the mining industry, because it prevents long-distance shipment in open cars. The neces-

¹⁵ Numbers refer to corresponding numbers on the map.



EXPLANATION



COUNTY, N. DAK.

sity for paying transportation charges on its high content of water is also a serious drawback to the development of the lignite industry.

In lignite of the best quality the weathered surfaces are black and have a bright, vitreous luster, even though the unweathered lignite is brown and has a dull luster. Where the woody texture is not developed the lignite weathers into thin plates or laminae, and the same property has been observed in certain of the low-rank subbituminous coals. The weathering of different varieties of lignite is so characteristic that the examination of the weathered face of an exposed section may afford a better conception of the variations in character within the bed than an examination of the fresh material.

CHEMICAL PROPERTIES.

In order to determine the chemical composition of lignite it is necessary to take mine samples, and as lignite changes not only in physical condition but chemically on exposure to the air, it is necessary that these samples be as fresh as possible. Three such mine samples were taken during the examination of the New Salem lignite field, in accordance with the regulations of the United States Geological Survey, which in brief are as follows: A channel is cut across a clean, fresh face of lignite from roof to floor of the mine, all partings that are thrown out in mining being excluded. The material thus obtained is broken sufficiently fine to pass through a one-half inch screen, and the sample is reduced by quartering to about 4 pounds. This is placed in a galvanized can, sealed, and sent immediately to the chemical laboratory of the Bureau of Mines at Pittsburgh, Pa., for analysis.

The analyses of these samples are shown in the accompanying table. With them are included for comparison the analyses of four samples taken by E. R. Lloyd in the Cannonball River lignite field, of three samples collected by A. L. Beekly in 1909 from small strip pits in the valley of Cedar Creek in T. 129 N., R. 88 W., and of seven representative samples of lignite from producing mines in widely separated parts of North Dakota. To these analyses are added those of two subbituminous coals, from Montana and Wyoming, and two eastern bituminous coals, from Ohio and Pennsylvania. These last four coals have a market in the New Salem field, and a comparison of their heating value with that of the local lignite is of great interest and importance.

The accompanying table shows each analysis in four forms, marked A, B, C, and D. Analysis A represents the composition of the lignite as it is taken from the mine. This form of analysis should not be used in comparing one coal or lignite with another, because the amount of moisture in the sample as it is taken from the mine depends

to a certain extent upon local conditions, and consequently analyses of different samples of the same lignite expressed in this form may vary widely. Analysis B represents the sample after it has been dried at a temperature a little above the normal until its weight becomes constant. Analysis C represents the lignite after all the moisture has been theoretically eliminated. Analysis D represents the lignite after all moisture and ash have been theoretically removed. Forms C and D are determined from the others by recalculation.

Analyses of coal samples from the New Salem lignite field, N. Dak.

[Made at the Pittsburgh laboratory of the Bureau of Mines; A. C. Fieldner, chief chemist.]

Lab- oratory No.	Name.	Location.			No. on map (P.L. V).	Let- ter in fig. 4.	Air- dry- ing loss.	Form of analy- sis.	Proximate.				Ultimate.						Heating value.	
		Quar- ter.	Sec- tion.	T. N. R. W.					Moist- ure.	Vola- tile mat- ter.	Fixed car- bon.	Ash.	Sul- fur.	Hy- dro- gen.	Car- bon.	Nitro- gen.	Oxy- gen.	Calo- rice.	British ther- mal units	
20033	Dakota Products Co.'s mine, near New Salem.	SW.	15	139	85	A	32.7	A B C D	38.5 8.6	27.6 41.1 44.9 50.9	26.6 39.5 43.3 49.1	7.28 10.83 11.84	1.31 1.96 2.13 2.42	7.03 5.04 4.47 6.07	39.22 38.31 63.79 72.36	0.60 .89 .98 1.11	44.56 22.98 16.79 19.04	3,725 5,535 5,055 6,870	8,700 9,970 10,900 12,360	
1901	Local mine.....	S. 1	32	138	84	51	31.5	A B C D	38.6 10.4	26.8 39.1 43.7 50.1	26.7 39.0 43.5 49.9	7.9 11.5 12.8	.66 1.97 1.07 1.23	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	3,885 5,230 5,835 6,686	6,450 8,430 10,500 12,060	
19786	Ramsland mine.....	NW.	6	137	86	B	24.9	A B C D	36.1 14.9 23.3 47.7	27.7 58.9 40.4 47.1	30.3 40.4 47.1 52.3	5.9 7.8 9.2	.41 .64 .58 .70	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	3,875 5,165 5,085 6,680	6,980 8,200 10,490 12,020	

Analyses of coal samples from fields furnishing coal in competition with the New Salem lignite.

Lab- or- atory No.	Name.	Location.			Let- ter in fig. 4.	Air- dry- ing loss.	Form of anal- ysis.	Proximate.			Ultimate.					Heating value.		
		Quar- ter.	Sec- tion.	T. N. R. W.				Moi- sture.	Vola- tile mat- ter.	Fixed car- bon.	Ash.	Sul- phur.	Hy- dro- gen.	Car- bon.	Nitro- gen.	Oxy- gen.	Calo- ries.	British ther- mal units.
14543	Nipper & Monroe's mine, near Haynes, N. Dak.	NW.	16	129	94	14.5	A B C D	32.6 21.2	30.6 35.8 45.4 51.8	28.5 33.3 42.3 48.2	8.3 9.7 12.3	1.53 1.70 2.27 2.69	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	4,085 4,790 5,070 5,920	7,380 8,600 10,920 12,460
14644	Pinkham mine, 9 miles northeast of Haynes, N. Dak.	NW.	36	130	94	15.3	A B C D	32.4 20.2	30.9 36.5 45.7 52.4	28.1 33.2 41.6 47.6	8.6 10.1 12.7	1.49 1.76 2.21 2.53	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	4,070 4,805 5,025 5,900	7,330 8,650 10,800 12,430
14729	Jones mine, near Leith, N. Dak.	SE.	12	133	88	27.1	A B C D	36.2 12.5	29.8 40.8 46.7 54.0	25.3 34.8 39.7 46.0	8.70 11.53 13.63	.68 .83 1.07 1.24	6.76 5.15 4.29 4.97	39.45 54.11 61.81 71.56	0.59 .81 .92 1.07	43.82 27.07 18.28 21.16	3,730 5,105 5,630 6,750	6,700 9,190 10,500 12,150
17637	Kolbank mine, near Leith, N. Dak.	NE.	7	133	87	16.6	A B C D	34.7 21.7	29.9 34.5 40.7 54.5	24.9 29.9 38.2 45.5	10.5 12.6 16.1	1.50 1.80 2.30 2.74	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	3,775 4,530 5,765 6,985	6,800 8,150 10,410 12,410
7841	Mine of A. L. McCord, Cedar Creek, N. Dak.	NE.	5	129	88	19.3	A B C D	32.1 15.8	25.6 31.8 37.8 44.8	31.7 39.2 46.6 55.2	10.6 13.2 15.6	1.19 1.48 1.75 2.07	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	3,790 4,685 5,580 6,615	6,820 8,460 10,040 11,910
7889	Surface prospect, Cedar Creek, N. Dak.	SW.	1	129	88	21.1	A B C D	33.1 15.2	25.5 32.4 38.2 41.5	30.1 45.7 53.9 59.5	5.3 7.7 7.9	.69 .87 1.03 1.12	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	4,150 5,255 6,200 6,735	7,470 9,460 11,160 12,120
7842	Surface prospect, Cedar Creek, N. Dak.	SE.	4	129	88	23.1	A B C D	32.5 12.2	27.1 35.3 40.1 43.9	34.6 45.0 50.1 56.1	5.8 7.6 8.6	.37 .48 .55 .69	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	4,080 5,240 6,065 6,625	7,250 9,480 10,740 11,780
1985	Mine of Washburn Lignite Coal Co., Wil- son, N. Dak.	.....	1	142	80	32.3	A B C D	40.5 12.2	27.1 38.9 45.5 48.7	27.4 40.4 46.0 50.3	5.0 7.5 8.5	.76 1.12 1.28 1.40	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	3,900 5,910 6,205 6,785	6,640 9,510 11,170 12,210

1971	Mine of Consolidated Coal Co., Lehigh, N. Dak.	8	139	95	D	35.5	A	43.1	24.5	25.7	7.7	1.13	7.28	38.11	40.66	5.420	5,150
							B	10.0	38.1	46.0	11.9	1.75	7.28	38.11	40.66	5,310	9,660
							C	.....	42.4	44.4	13.2	1.95	7.28	38.11	40.66	5,005	9,660
							D	.....	43.8	51.2	.....	2.25	7.28	38.11	40.66	6,905	12,240
19367	Mine of U. S. Reclamation Service 3 miles northeast of Williston, N. Dak.	7	154	100	E	32.8	A	44.1	35.4	26.3	5.76	.56	7.28	38.11	40.66	3,355	5,040
							B	15.9	35.4	39.1	8.58	.64	7.28	38.11	40.66	4,000	5,040
							C	.....	42.6	47.1	10.32	1.00	4.26	64.68	1.13	10,810	10,810
							D	.....	47.5	52.5	.....	1.12	4.74	72.11	1.26	6,005	12,000
14435	Scranton mine of Charles Liddell, Scranton, N. Dak.	24	131	100	SW.	22.5	A	34.8	31.1	26.0	8.1	.56	7.28	38.11	40.66	3,540	5,920
							B	15.9	40.1	33.5	10.5	.85	7.28	38.11	40.66	4,980	8,920
							C	.....	47.7	39.8	12.5	1.01	7.28	38.11	40.66	5,500	10,610
							D	.....	54.5	45.5	.....	1.15	7.28	38.11	40.66	6,730	12,120
33069	Beulah mine, Mercer County, N. Dak.	25	144	88	F	26.9	A	34.8	28.2	30.8	6.20	.70	6.73	42.41	40.66	4,005	7,210
							B	10.9	38.5	42.1	8.48	.90	6.73	42.41	40.66	5,490	9,860
							C	.....	43.2	47.3	9.51	1.07	4.39	65.07	1.06	6,145	11,000
							D	.....	47.8	52.2	.....	1.18	4.85	71.91	1.17	6,700	12,230
32444	Hebron Fire & Pressed Brick Co.'s mine, Hebron, Morton County, N. Dak.	.....	140	90	G	.....	A	28.1	31.1	31.4	9.41	1.15	5.97	44.58	39	4,075	7,340
							B	19.0	35.1	35.3	10.59	1.29	5.32	50.16	66	4,565	8,000
							C	.....	43.3	43.6	13.06	1.60	3.97	61.89	82	5,265	9,830
							D	.....	49.8	50.2	.....	1.84	4.57	71.19	94	6,510	11,720
31705	Canon mine of J. F. Casteele, Burlington, Ward County, N. Dak.	.....	150	84	H	30.1	A	37.0	24.9	27.7	10.43	.22	6.39	37.36	61	3,340	6,010
							B	9.8	35.6	39.7	14.92	.32	4.38	53.44	57	4,400	8,000
							C	.....	39.5	44.0	10.54	.35	3.63	59.23	97	5,265	9,830
							D	.....	47.3	52.7	.....	.42	4.35	70.97	1.16	6,345	11,420
12005	Monarch mine of Wyoming Coal & Coke Co., Monarch, Sheridan County, Wyo.	24	57	85	I	11.1	A	22.3	35.0	39.0	3.73	.37	6.27	55.28	1.07	5,245	9,620
							B	12.5	39.4	43.9	4.20	.42	5.67	62.18	1.20	6,010	10,520
							C	.....	45.0	50.2	4.80	.48	4.89	71.10	1.38	6,870	12,370
							D	.....	47.3	52.7	.....	.50	5.14	74.68	1.45	7,220	12,990
29004	Mine A of Roundup Coal Mining Co., Roundup, Musselshell County, Mont.	22	8	25 E.	J	3.5	A	13.6	32.8	45.5	8.05	.70	5.56	61.98	.98	5,925	10,690
							B	10.5	34.0	47.2	8.34	.72	5.37	64.20	1.01	6,150	11,070
							C	.....	38.0	52.7	9.31	.81	4.69	71.70	1.13	6,870	12,360
							D	.....	41.9	58.1	.....	.89	5.17	79.06	1.26	7,575	13,630
7712	Hooking Valley, Ohio.	.....	.....	.....	K	5.5	A	9.8	32.4	53.4	4.43	.54	5.70	69.50	1.25	8,905	12,250
							B	4.5	34.3	56.5	4.69	.67	5.38	73.55	1.32	9,200	12,900
							C	.....	35.9	59.2	4.91	.60	5.12	76.99	1.38	7,535	13,570
							D	.....	37.8	62.2	.....	.68	5.38	80.96	1.45	7,925	14,270
22007	Pittsburgh coal, East Millsboro, Fayette County, Pa.	.....	.....	.....	L	1.2	A	2.5	35.7	53.6	8.17	1.76	5.19	76.15	1.49	7,865	13,650
							B	1.4	36.1	54.2	8.27	1.75	5.12	77.08	1.51	7,675	13,520
							C	.....	38.6	55.0	8.38	1.81	5.04	78.13	1.53	7,780	14,000
							D	.....	40.0	60.0	.....	1.99	5.50	85.28	1.57	8,490	15,230

20083. From mine of Dakota Products Co. (location 64), half a mile north-east of New Salem; collected by E. T. Hancock October 23, 1914, about 2,540 feet N. 20° W. of the mine mouth. The lignite bed is in the Fort Union formation and ranges from 4 feet 6 inches to 6 feet in thickness. At the point of sampling the top of the bed was not exposed, and the sample included that part of the upper bench worked, 1 foot 4 inches thick, and the bottom bench, 3 feet 1 inch thick.

19801. From a local mine (location 51) operated by farmers in the S. $\frac{1}{2}$ sec. 32, T. 138 N., R. 84 W.; collected by E. T. Hancock September 7, 1914, at a point about 70 feet N. 15° W. of the shaft. The lignite bed is in the Fort Union formation and is 6 feet 8 inches thick, but only the lower 4 feet 8 inches of the bed was sampled.

19786. From Ramsland open-pit mine (location 2), in the NW. $\frac{1}{4}$ sec. 8, T. 137 N., R. 86 W.; collected by E. T. Hancock August 24, 1914. The lignite bed is in the Fort Union formation and at the point of sampling has a thickness of 6 feet 9 $\frac{1}{2}$ inches, but only the upper 3 feet 11 inches of the top bench was sampled.

14542. From Haynes lignite bed in the Nipper & Monroe mine, 3 $\frac{1}{2}$ miles north-east of Haynes; collected by E. R. Lloyd July 30, 1912, in entry about 630 feet nearly due east of the mine mouth.

14544. From Haynes lignite bed in mine of William Pinkham, about 9 miles northeast of Haynes; collected by E. R. Lloyd July 30, 1912, in main entry about 225 feet south of the mine mouth.

14729. From Haynes (?) lignite bed in Jones mine of J. T. Dunn, about 2 miles west of Leith; collected by E. R. Lloyd September 7, 1912.

17537. From Haynes (?) lignite bed in Kolbank mine of Simon Pederson, about 1 $\frac{1}{2}$ miles southwest of Leith; collected by E. R. Lloyd July 10, 1913.

7841. From McCord mine (strip pit), on the north side of Cedar Creek, in the NE. $\frac{1}{4}$ sec. 5, T. 129 N., R. 88 W., about 8 miles northeast of Morristown, S. Dak.; collected by A. L. Beekly in 1909.

7839 and 7842. From prospect pits on the south side of Cedar Creek, T. 129 N., R. 88 W.; collected by A. L. Beekly in 1909. They are from the same bed as sample 7481.

1935. From mine of Washburn Lignite Coal Co., Wilton, McLean County, N. Dak.; collected by M. R. Campbell August 3, 1905, 1,750 feet from shaft.

1971. From mine of Consolidated Coal Co. at Lehigh, Stark County, N. Dak.; collected by M. R. Campbell August 5, 1905, 1,900 feet from the mine mouth.

19867. From mine of United States Reclamation Service 3 miles northeast of Williston, Williams County, N. Dak.; collected by F. A. Herald August 16, 1911, 1,225 feet east of the mine mouth.

14485. From Harmon (?) lignite bed in Scranton mine of Charles Liddell, Scranton, Bowman County, N. Dak.; collected by C. J. Hares June 30, 1912, from face of east entry, 1,000 feet from mine mouth.

33069. From Beulah mine, Beulah, Mercer County, N. Dak.; collected by A. J. Collier October 6, 1919, in ninth entry north.

32444. From Hebron mine of Hebron Fire & Pressed Brick Co., Hebron, Morton County, N. Dak.; collected by B. W. Dyer March 13, 1919.

31705. From Conon mine of J. F. Casteel, Burlington, Ward County, N. Dak.; collected by John G. Schoning March 28, 1919.

12005. From Monarch mine of Wyoming Coal & Mining Co., Monarch, Sheridan County, Wyo.

29004. From mine A of Roundup Coal Mining Co., Roundup, Musselshell County, Mont.

7712. From Hocking Valley, Ohio.

23097. From East Millsboro, Fayette County, Pa.; a typical Pittsburgh coal.

The percentage of moisture in all lignites is very high. The percentage of sulphur shown in the analyses of lignites from this field is higher than that in the lignites of some parts of the plains basins, but it is not so high as that in coals of other regions. The sulphur occurs in the form of nodules or balls of pyrite and marcasite, which are distributed along joints and bedding planes.

In the analyses of samples from the New Salem and Cannonball River lignite fields and some of the others given in the above table the volatile matter was determined by the "modified method," which involves a preliminary heating of the lignite before it is subjected to a temperature sufficiently high to drive off the volatile matter. The modified method prevents the sputtering and the attendant mechanical loss of particles of the sample which are caused in the standard method where the higher heat is applied at once. The loss accompanying the standard method affects chiefly the fixed carbon, so that when the modified method is used the determined percentage of that constituent is generally higher, in some analyses as much as 20 per cent.

COMPARATIVE HEATING VALUE.

Most of the users of lignite are little concerned about the percentage of sulphur in the lignite or even the relative amounts of volatile matter and fixed carbon, but they are vitally interested in the heat-producing quality of the lignite, for this determines its value for ordinary purposes, such as heating buildings, raising steam, and general use in manufacturing plants.

Many think it best to foster home industries even at the cost of some sacrifice, but to most persons the deciding factor regarding a fuel as well as any other commodity that they may be needing is that of economy, and economy in the purchase of fuel means generally getting the fuel with the greatest heating power for the least money. Lignite is so different from bituminous coal that most persons are unable to make a direct comparison, but such a comparison is essential in order to determine which kind of coal is the most economical to use. The ordinary analysis of a coal will not furnish the data directly for the comparison, but the calorific determinations given in the table on page 17 will enable anyone to make a direct comparison of the various coals and lignites there listed, and in fact their comparative values may be expressed in dollars and cents.

Figure 4 shows graphically the heating value of certain of the coals and lignites whose analyses are given on pages 17-19. These analyses have been selected because they were made from samples that were collected in working mines and so had suffered no deteriora-

tion from exposure to the weather. For convenience in reference these will be designated A, B, C, etc., as shown in the diagram. A and B represent samples from the New Salem field; C to H lignite from adjacent fields of North Dakota; I and J subbituminous coals from Wyoming and Montana; and K and L two well-known and high-rank coals from the East that are frequently shipped into this region by way of the Great Lakes. These letters are also shown in the table of analyses.

The line marked "pure coal" shows the comparative heating value of the several coals in nearly the pure form—that is, after the moisture and ash, the ordinary impurities, have been eliminated. This line so far as it concerns the lignite is nearly horizontal, showing that, in their pure form the lignites differ but little in their heating value. According to this line the lignites here considered rank

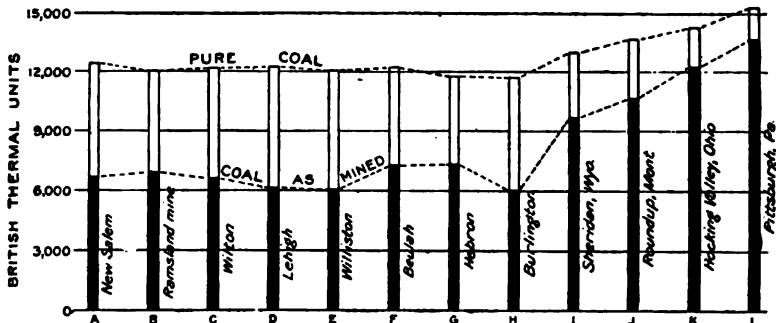


FIGURE 4.—Graph showing the heating value of North Dakota lignite as compared with that of other coals with which it may have to compete.

as follows: A, D, F, C, B, E, G, H. In other words, the New Salem lignite is intrinsically a little better than any other lignite here considered. The "pure coal" line ascends rapidly to the right, reaching its highest point at L. This shows that the best coal here considered is the Pittsburgh coal, and that both this and the Hocking Valley coal of Ohio are superior in heating value to the subbituminous coals of Wyoming and Montana.

The comparison just made is interesting, but it has no practical value because it refers to pure coal and not to the coal in the consumer's bin. The line marked "coal as mined" shows the comparative heating value of the same group of coals in approximately the condition in which they are consumed. This line shows much greater variations than the "pure coal" line because it involves not only inherent differences in the coal substance but also differences due to the presence of ash and moisture, both of which are very detrimental to a fuel. The lignites stand in the following order: G, F, B, A, C, D, H, E. The Hebron mine produces the best lignite,

with Beulah a close second and Ramsland third. Here again the subbituminous and bituminous coals stand higher than the lignites, and the difference between them is more marked than it is on the "pure coal" line. The reason for this is mainly the fact that the high-rank coals contain little moisture, whereas lignite is heavily charged with moisture.

The relative heating values are proportional to the British thermal units in the analyses showing coal "as received." Thus, the heating value of New Salem lignite compared with that of Pittsburgh coal is as 6,700 is to 13,650; or, expressed in another way, if New Salem lignite sells for \$5 a ton the consumer could afford to pay \$10.20 for Pittsburgh coal. If he could buy Pittsburgh coal for less than \$10.20 it would be cheaper than the lignite at \$5. If New Salem lignite costs \$5 a ton the real value of the other lignites and coals shown in the diagram is as follows:

Comparative value of certain coals.

New Salem lignite.....	\$5. 00
Ramsland lignite.....	5. 05
Wilton lignite.....	4. 98
Lehigh lignite.....	4. 60
Williston lignite.....	4. 44
Beulah lignite.....	5. 40
Hebron lignite.....	5. 45
Burlington lignite.....	4. 49
Sheridan subbituminous coal.....	7. 20
Roundup subbituminous coal.....	7. 95
Hocking Valley bituminous coal.....	9. 15
Pittsburgh bituminous coal.....	10. 20

MINING.

At the time the field work was done the only mine in operation was that of the Dakota Products Co., at New Salem.* This mine, which is considered in the description of T. 139 N., R. 85 W., was almost a continuous producer, while practically all the other local mines are operated for only a short period each year and only on a very small scale.

The Dakota Products Co.'s mine was operated almost entirely to supply the local demand for lignite. The tonnage mined during the fall and winter greatly exceeded that produced during the spring and summer, but the average daily output for the year was reported to be about 110 tons. Some of the lignite was consumed in New Salem and some was hauled in wagons directly from the mine to the farms of the surrounding country. A considerable quantity was also

* This mine has since been abandoned, but in 1919 the Consolidated Lignite Collieries Co. was opening a new mine in sec. 7, about 3 miles northwest of New Salem.

shipped by rail to the small towns on the Northern Pacific Railway and from them distributed by wagons.

It has apparently been the custom throughout this field for two or more farmers to combine and by means of plows and scrapers remove the cover from a bed of lignite. After the covering is removed the lignite is broken up by some convenient method and shoveled directly into wagons. With very few exceptions the local lignite mines represented on the accompanying map (Pl. V) are openings of this character. They are generally referred to as "open-pit mines" or "strip pits," and the process of removing the overburden is known as "stripping." In most of them only a few hundred square feet of the lignite bed has been removed, but exceptionally—for example, at the large open pits at locations 2, 3, 4, and 5, about $3\frac{1}{2}$ miles southwest of Almont—several thousand square yards of the beds have been stripped and mined out.

The lignite beds in this field are almost without exception underlain by a dense bluish-gray clay shale, which is nearly impervious to water. Such material is a very serious obstacle to open-pit mining, for after the covering is removed and a portion of the lignite is mined out the open pit readily fills with water. Many of the open pits can not be drained without the expenditure of considerable additional labor. This difficulty could be avoided by selecting for stripping some point on a slope where the pit could be more easily drained. Too often the place chosen for stripping is determined by certain signs of lignite, such as black material brought up by burrowing animals, without the slightest regard for the possibility of draining the pit after it is made. Owing to a heavy rainfall early in the season of 1914, practically all the open pits in the New Salem field were partly filled with water, a condition which made it very difficult in many places to measure the thickness of the lignite beds.

The ground water moves downward until it reaches the impervious clay shale and then flows laterally, eventually reaching the surface in the form of springs. In opening drift mines it is advantageous to determine the local conditions of structure and then locate the mine in such a manner that the entry will follow the gradual rise of the beds, which in most localities is sufficient to furnish natural drainage.

One of the most serious obstacles to underground mining in this field is the character of the overlying shale, which is so weak that it can not be used as a roof. It is therefore necessary in many places to leave a portion of the lignite to form the roof, a necessity which prevents the mining of any but the thicker beds by this method.

A general estimate of the amount of coal present in the New Salem field may be obtained after a study of the stratigraphic sections

given for each township. Taking an average of the mean thicknesses of coal beds for each township gives 3.03 feet as a uniform thickness for the entire field. On the assumption that 1 square mile of lignite 1 foot thick contains 1,152,000 short tons, a thickness of 3.03 feet for the New Salem field will give it a coal content of approximately 2,068,000,000 short tons.

DESCRIPTION BY TOWNSHIPS.

The lignite beds in each township are described in order, beginning with the lowest. All places where lignite beds were examined and many places where lignite was reported to be present were accurately located, and their positions are shown on the maps by location numbers. The lignite sections measured at these points are correspondingly numbered, and it is by means of these numbers that reference is made from the text to the map (Pl. V) and to the plate of graphic sections (Pl. III).

T. 137 N., R. 82 W.

The most conspicuous topographic feature in T. 137 N., R. 82 W., is the prominent ridge composed mainly of glacial boulders which occupies a portion of secs. 13, 14, 23, and 24. All the northern part of the township is a gently rolling upland underlain by the Cannonball marine member of the Lance formation. Most of the south half is considerably lower than the northern upland and is almost flat, and although there are no rock exposures, it is probably underlain by the lower part of the Lance formation. Most of the drainage from the township empties into Little Heart River. With the exception of the small boulder-covered tract mentioned above, the entire township is well adapted to agriculture. No exposures of lignite were observed.

T. 138 N., R. 82 W.

With the exception of an area of about 10 square miles in the southeast corner, T. 138 N., R. 82 W., drains into Heart River. The surface of the township, except a narrow belt adjacent to Heart River and Sweetbriar Creek, is a gently rolling prairie well suited to agriculture. The very fertile alluvium along the principal streams is admirably adapted to general farming, and the deeply dissected belt adjacent to it is utilized mainly for grazing.

Nearly all of the township is occupied by the Cannonball member of the Lance formation. The lower sandstones of the Fort Union formation cap some of the highest buttes, which occur principally in the southwestern and northeastern parts of the township. No outcrops of lignite were seen, and none were reported.

T. 139 N., R. 82 W.

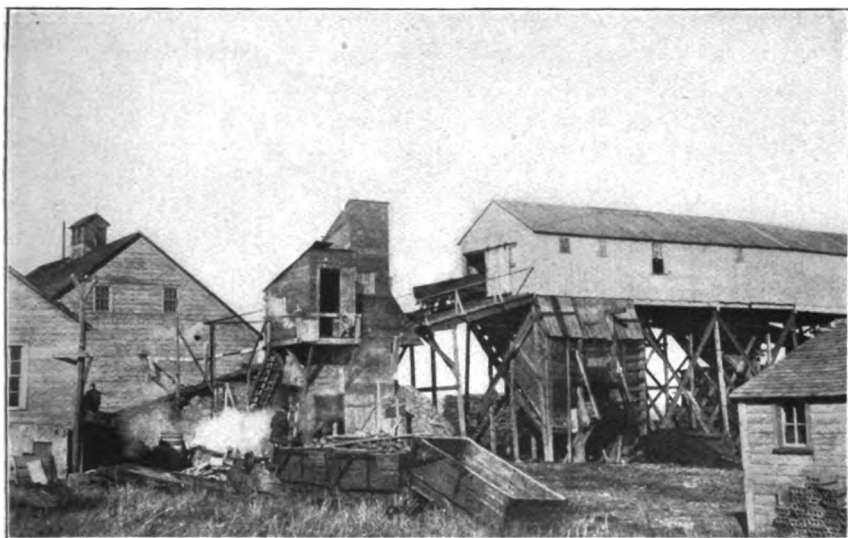
Heart River flows across the southeastern part of T. 139 N., R. 82 W., and receives the drainage from all except the north tier of sections. In general the eastern and southeastern parts of the township are moderately rough, owing to the extent to which the numerous small streams have eroded the soft shale. The northwestern part, on the other hand, is a rolling prairie. The alluvial flat along Heart River and the moderately level upland are devoted to general farming; the rougher portions of the township are utilized mainly for grazing. The township is crossed by the main line of the Northern Pacific Railway, on which grain elevators have been erected at short intervals, bringing the producers into close touch with the markets.

The Fort Union beds have been eroded so that the underlying marine member of the Lance formation is exposed throughout about two-thirds of the township. The comparatively high upland in the northwestern part is composed of the lower beds of the Fort Union formation.

Only one bed of lignite was observed in this township. From its position with reference to the base of the Fort Union formation it was designated bed A. The bed was measured in an open pit at location 29, in sec. 10, where it was found to consist of at least two separate benches of lignite separated by 8 inches of black carbonaceous shale. The upper bench measured 1 foot 6 inches, but all except the upper 10 inches of the lower bench was under water and its full thickness could not be ascertained. It was reported, however, to have a total thickness of 3 feet. What is probably the same bed was seen in an old prospect in the SW. $\frac{1}{4}$ sec. 15. Its position was also indicated by a "burn" in the SW. $\frac{1}{4}$ sec. 9, and the bed was measured in the road at location 28, in sec. 8, where it was found to contain only 1 foot 5 inches of lignite. What is believed to be the same bed is also exposed near the east line of sec. 12 of the township immediately west. As the bed at that place appeared to contain only 10 inches of lignite, the line of traverse was not continued west of location 28.

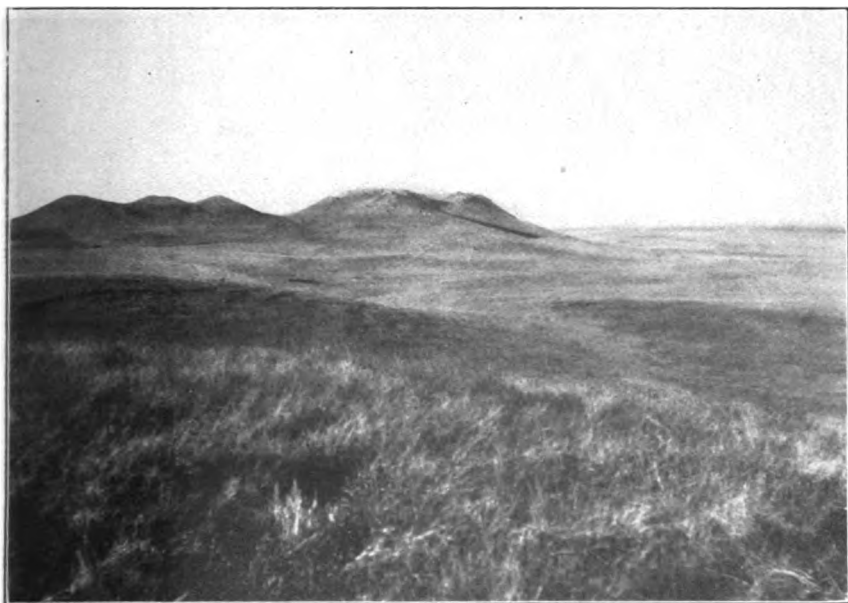
T. 140 N., R. 82 W.

The drainage of T. 140 N., R. 82 W., goes eastward into Missouri River, which lies from 2 to 3 miles east of the township. Otter Creek drains much the larger part of the township. All of the eastern part is underlain by the Cannonball marine member of the Lance formation; the western part is occupied by the lower beds of the Fort Union. The portion of the township underlain by the Lance formation has a very uneven surface. The slopes are not steep,



A. DAKOTA PRODUCTS CO.'S MINE NEAR NEW SALEM, N. DAK.

This mine has been abandoned.



B. CROWN BUTTE, ON UPLAND IN SEC. 31, T. 140 N., R. 82 W., N. DAK.. LOOKING NORTHEAST.

however, so that the valleys and much of the upland are well adapted to farming. South of Square Butte Creek the edge of the Fort Union formation is marked by a rather steep escarpment, and below the escarpment for a distance of half a mile to a mile the land is deeply dissected. The portion of the township which is occupied by the Fort Union formation maintains a somewhat higher altitude and has a much more even surface than the other portion. In places there are prominent hills or buttes, as they are called in this country, standing distinctly above the surrounding plain. One of the best examples is Crown Butte, shown in Plate IV, B.

A single bed of lignite was found in this township, and from its relation to the base of the Fort Union formation it was identified as bed A. At location 30, in the NW. $\frac{1}{4}$ sec. 17, the bed contains 4 feet 1 inch of good lignite overlain by black carbonaceous shale and underlain by gray clay shale. This bed does not appear to be of much value for any considerable distance north of location 30, for the section measured in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 9 includes only a few thin streaks of lignite. The bed was at one time extensively mined for local use near the southeast corner of sec. 20, but the workings have been abandoned and allowed to fill with water. What was taken to be the same bed is exposed in a spring about 600 feet east and a little north of the southwest corner of sec. 29. The thickness of the bed at this place is reported to be 1 foot 6 inches. No further exposures of this bed were observed during the geologic mapping. On Plate V the broken line in secs. 19, 30, and 31 indicates the probable position of bed C, which in this township is entirely grass-covered.

T. 137 N., R. 83 W.

The most prominent surface feature in T. 137 N., R. 83 W., is the high drainage divide which crosses near the middle of the township in a north-south direction. This divide is roughly coincident with the area underlain by the rocks of the Fort Union formation. The shale and soft sandstone of the Cannonball marine member of the Lance formation west of the divide are deeply dissected by numerous small streams, and in consequence the area is extremely rough and, except for the alluvial flats along Heart River, is ill adapted to general farming. The area occupied by the same member east of the divide, on the other hand, slopes off gently to the lowland. It is gently rolling, whereas the area mapped as lower Lance is almost perfectly flat. The part of the township east of the divide is well adapted to general farming.

Two noteworthy beds of lignite are exposed in this township and from their stratigraphic positions were designated beds B and D. Their outcrops are shown on Plate V, and the sections measured at

short intervals are represented graphically on Plate III. By referring to sections 57, 58, 59, 60, 61, and 62 it will be seen that the lower bed (bed B) ranges in thickness from 2 feet 2 inches to 4 feet 10 inches. The rock overlying this bed is commonly a light-colored soft sandstone, and that underlying it is commonly a clay shale. The upper bed (bed D) was found only at location 17, near the northwest corner of sec. 30, and at an old prospect in the SE. $\frac{1}{4}$ sec. 20. At location 17 the bed contains 2 feet 6 inches of lignite with a $\frac{1}{4}$ -inch shale parting 6 inches from the top. At the old prospect in sec. 20 the bed contains 2 feet 6 inches of very much weathered lignite.

T. 138 N., R. 83 W.

Heart River crosses T. 138 N., R. 83 W., in a series of great meanders from the SE. $\frac{1}{4}$ sec. 31 to the SE. $\frac{1}{4}$ sec. 18. The alluvial flat in which the river flows and which ranges from a quarter to half a mile in width (Pl. I, B) includes some of the most fertile agricultural land in the township. As in other parts of the field, the rich flood plain of the river is bordered on either side by a belt of country from half a mile to a mile in width in which numerous side streams have deeply intrenched themselves in the soft sandy shale of the Lance formation. This belt is better suited for grazing than for general farming. It gradually merges into the gently rolling upland, which if not entirely underlain by the Fort Union beds is characterized by small isolated buttes that are merely outliers of that formation. No lignite was seen or reported in this township.

T. 139 N., R. 83 W.

With the exception of a narrow belt along the east edge, T. 139 N., R. 83 W., drains into Sweetbriar Creek. Although this township is traversed by a great many drainage channels, most of the valleys are comparatively shallow, and general farming can be carried on nearly everywhere. Sweetbriar Creek and its numerous tributaries have gradually eroded away the overlying Fort Union beds, exposing the underlying sandstone and sandy shale of the Lance formation throughout most of the south half of the township. This broad valley of erosion gradually merges into the upland occupied by the Fort Union formation. The flatness of the upland is indicated by the paucity of drainage channels and also by the fact that most of the public highways follow the section lines. The small settlement known as Sweetbriar, on the main line of the Northern Pacific Railway, affords an excellent market and shipping point for the surrounding region.

The only exposures of lignite seen in this township are on bed A at locations 26 and 27, in sec. 4. The details of the sections measured

at these points are represented in Plate III. It is reported that a well in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 3 passed through 4 feet of lignite at a depth of about 40 feet. From the elevation of the surface at that place the lignite bed as reported is 12 feet lower than the lignite at locations 26 and 27 and in all probability represents the same bed.

T. 140 N., R. 83 W.

A drainage divide that is not at all conspicuous as a surface feature crosses T. 140 N., R. 83 W., from the southwest corner of sec. 6 to the southeast corner of sec. 24. This divide separates the drainage which flows north and east into Square Butte Creek from that which flows south into Sweetbriar Creek. The only rocks exposed in this township are those of the Fort Union formation. In contrast with the dissected belt along Heart River the entire township is a gently rolling upland prairie, suitable for general farming. It is well settled, and with few exceptions the main wagon roads follow the section lines.

Owing to the evenness of the surface it is extremely difficult to find exposures of lignite, but measurements of a bed were obtained at locations 38, 39, 40, 41, and 42. As shown on Plate III, the bed is thin, not exceeding 2 feet 8 inches in thickness at any of these locations. From the elevation of the lignite at these places it is reasonable to assume that they represent the same bed, which, upon the basis of its stratigraphic position, is assumed to be bed C. A 4-foot bed of lignite is exposed in an open pit at location 65, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 13 of the township immediately west, and in all probability represents a higher bed, but no exposures of the upper bed were observed in this township.

T. 137 N., R. 84 W.

The drainage from the western part of T. 137 N., R. 84 W., flows westward and empties into Beaver Creek; that from the eastern part flows eastward and empties into Heart River. The divide between the two drainage systems crosses the township in a north-south direction about a mile west of its middle line. The soft sandstone and sandy shale of the Lance formation on either side of Heart River back for a distance of $1\frac{1}{2}$ or 2 miles are deeply dissected by numerous side streams, and in consequence this badland is used mainly for grazing. A well-defined flood plain from a third to half a mile in width extends along Heart River and includes some of the most fertile land in the township. The deeply dissected belt on either side of the river valley gradually merges into the gently rolling upland, which is underlain by the lower beds of the Fort Union formation. The lower part of the Lance formation extends up

Heart River for a distance of about 4 miles and crops out in a narrow belt between the alluvium and the upper or Cannonball member of the Lance. The exposures of lignite in this township are all believed to represent the same bed, which, on the basis of its stratigraphic position, is correlated with bed B in the township immediately east. The sections measured at locations 53, 54, 55, and 56 show a bed of lignite ranging from 2 feet 5½ inches to 6 feet 4 inches in thickness. The details of the sections are graphically represented on Plate III. A bed of lignite 80 inches thick at location 51, in sec. 32, T. 138 N., R. 84 W., is from its elevation believed to be the same bed.

T. 138 N., R. 84 W.

From the west-central part of T. 138 N., R. 84 W., the streams flow north into Sweetbriar Creek, east into Heart River, and south into Beaver Creek. Fort Union beds crop out in about two-thirds of the township, and that portion has a gently rolling surface well adapted to agriculture. Some of the area underlain by the Cannonball marine member of the Lance formation is extensively cut up by deep gullies and is suited only for grazing. It shows in many places steep grass-covered ridges with buttes of the Fort Union formation rising abruptly above the general surface. A large part of the township is covered by a mantle of glacial till with pebbles and boulders ranging from coarse gravel to boulders the size of a small house. Certain tracts are so thickly covered with the glacial drift as to be useless for anything but grazing.

Only one bed of lignite of economic importance was observed in this township. This bed ranges from 3 feet to 6 feet 8 inches in thickness, and it is believed to be bed B, the same as the one mapped in the township immediately south. The details of the measurements made at locations 49, 50, 51, 52, and 63 are represented graphically on Plate III. Where the thickness of the bed was found to be below the classifiable limit of 28 inches it is not represented graphically. Thus at location 70, in sec. 1, bed B measures only 2 feet 3 inches; at location 71 it appears to be represented by two thin streaks of carbonaceous shale; and at a point near the west line of sec. 15 it contains only 1 foot 3 inches of lignite. A bed of lignite 1 foot 10 inches thick was measured near the bottom of the valley in the NE. ¼ sec. 6. No other exposures were observed, and owing to the local northeasterly dip it was impossible to correlate the bed with any of the other beds mapped.

T. 139 N., R. 84 W.

In T. 139 N., R. 84 W., Sweetbriar Creek and its northern tributary have lowered their beds enough to expose the Lance formation only in a small tract in the southeastern part of the township. A

narrow belt along the contact between the Fort Union and the Cannonball member of the Lance formation is in many places very rough, owing to the presence of numerous small gullies. The eastern part of sec. 12, parts of secs. 35 and 36, and some other tracts are covered with glacial boulders (Pl. II, A). Such tracts are ill adapted to general farming but can be utilized to good advantage for grazing. The flood plains along the principal streams and most of that portion of the township which is underlain by the Fort Union formation are well adapted to general farming. The main line of the Northern Pacific Railway crosses this township from east to west. The little town of Judson, situated on the railway about a mile south of the center of the township, affords a market and shipping point for the crops raised in the surrounding region.

A bed of lignite was observed at location 23, in sec. 2, and at locations 19, 20, 21, and 22, in secs. 29 and 30. As shown in Plate III, the bed at these locations contains from 1 foot 5 inches to 5 feet 8 inches of lignite, but the thicker section is badly broken by partings. These exposures are all believed to be on the lowest bed observed in the field, namely, bed A.

T. 140 N., R. 84 W.

T. 140 N., R. 84 W., except a small tract in the northeastern part, is drained by the branches of Sweetbriar Creek. The entire township is occupied by rocks of the Fort Union formation. It comprises a portion of the gently rolling upland prairie that forms the divide between Sweetbriar and Square Butte creeks. The extent to which the public highways are able to follow the section lines expresses the evenness of the surface. The amount of land in this township at present being farmed is indicated by the more or less uniform distribution of farm houses.

The few exposures of lignite that occur in this township are believed to represent at least three different beds. The bed exposed at location 25, in sec. 31, and at the two open pits at location 24, in sec. 34, occurs only a short distance above the base of the Fort Union formation, and accordingly it is assumed to be bed A. This bed, as shown in Plate III, is 4 feet 1½ inches thick, including a parting 5½ inches thick, at location 24, but at location 25 the part exposed is only 2 feet 6 inches thick and consists of bony lignite. The 3-foot 8-inch bed of lignite exposed in the open-pit mine at location 16, in sec. 16, is believed to be bed D, whereas the 4-foot bed of lignite exposed in the open pit at location 65, near the east line of sec. 13, is at a position stratigraphically somewhat higher and was accordingly correlated with bed E.

Lignite is said to have been found in several wells in this township. For example, a 4-foot bed of lignite is reported in the log of

a well a few hundred feet southeast of the house in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 14, at such a depth that its elevation is 2,147 feet, or the same as that of the lignite at location 65. Some lignite is also reported in the log of a well near the house in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 2, at such a depth that the elevation is 2,180 feet, but the thickness of the bed could not be ascertained. Furthermore, 6 feet of lignite is reported in the log of a well near the house in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 10, at such a depth that it would have an elevation of 2,095 feet. The elevation of the bed in the well is so near that of the bed in the open-pit mine in sec. 16 that it seems probable that they are the same. What appears from its elevation to be the same bed is reported to occur at a depth of 35 feet in a well near the house in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 12, T. 140 N., R. 85 W. This 7-foot bed of lignite, reported to have been "dug through," was found to have an elevation of 2,082 feet.

T. 137 N., R. 85 W.

The most conspicuous topographic feature in T. 137 N., R. 85 W., is the relatively high divide which separates the Big Muddy Creek drainage system from that of Beaver Creek. Each of these streams flows in very striking meanders, and each has a well-defined flood plain, which includes some of the most fertile land in the township. That of Big Muddy Creek averages about three-quarters of a mile in width, but that of Beaver Creek has a width of less than a quarter of a mile. Bordering the flood plain of each stream is a belt of badlands which has been deeply dissected by numerous small streams and which is better adapted for grazing than for general farming. The badland belt gradually merges into the gently rolling upland prairie. The Cannonball member of the Lance formation is exposed throughout most of the south half of the township, and the Fort Union or lignite-bearing formation occupies practically all of the north half.

The exposures of lignite that were examined are believed to represent two separate beds, which, from their relation to the base of the Fort Union formation, are assumed to be beds A and B. The lower, or bed A, is of very little value, containing in the NE. $\frac{1}{4}$ sec. 4 only 1 foot 6 inches of very poor lignite. Even for immediate local use this bed has been abandoned. The upper bed is represented by a number of very striking "burns" on the west side of the ridge. The lignite is exposed only at the side of the main road in sec. 10 (location 44), where, as shown in Plate III, it is 2 feet 10 inches thick. Bed B in T. 137 N., R. 86 W., is represented by a thin band of lignite from 3 to 7 inches in thickness. In order to determine the dip of the rocks the thin lignite bed was traversed throughout that township, as well as in secs. 19 and 30 of this township.

T. 138 N., R. 85 W.

A high ridge covered by a thick mantle of glacial boulders extends from north to south through T. 138 N., R. 85 W., and separates it into two almost equal parts. A somewhat less prominent parallel ridge lies immediately east of Beaver Creek.

This township is occupied throughout by the lignite-bearing Fort Union formation. Exposures of lignite were observed at a number of places, but owing to the local irregularity of structure (see p. 12) it is extremely difficult to correlate them. According to what appeared to be the most reasonable interpretation the different sections represent beds A, B, C, and D. It is highly probable that the two beds exposed in sec. 4 (locations 12 and 34) are the same as the beds exposed in sec. 8 (locations 11 and 33), as the upper bed was traced from one to the other area by means of a succession of "burns." The very appreciable dip toward the southwest may cause the lower one of these two beds (bed C) to dip beneath the two streams and to reappear in sec. 12, T. 138 N., R. 86 W.

Bed A is exposed at locations 31 and 32, in sec. 33; location 66, in sec. 29; and location 67, in sec. 30. At location 31, as shown in Plate III, it has a thickness of 3 feet 8 inches, and at the open-pit mine at location 32 the principal bench of lignite measures 2 feet 4 inches, but above it there is an 11-inch bed of lignite separated from the main bed by 15 inches of carbonaceous shale. This bed has been mined at one or two other places near by, but the mines were long ago abandoned, and the old openings have caved so badly that the bed could not be measured. Bed A is reported to have a thickness of 4 feet on the line between secs. 28 and 33, but a measurement could not be obtained. At location 66, in sec. 29, bed A is 2 feet 3 inches thick, and at location 67, in the SE. $\frac{1}{4}$ sec. 30, 1 foot 9 inches.

Bed B is more than 4 feet thick at locations 47, in sec. 28, and 48, in sec. 26, at each of which the bottom of the bed was under water and the entire thickness could not be ascertained. At location 68, in sec. 30, the bed measured 1 foot 9 inches, and at location 69, 1 foot 10 inches. It is apparent, therefore, that bed B in traversing the township from sec. 21 to sec. 26 ranges in thickness from 1 foot 9 inches to 4 feet 8 inches or more.

The principal exposures of beds C and D occur in secs. 4, 5, 6, 8, and 18. At locations 33, 34, and 35 bed C ranges in thickness from 3 feet 6 inches to more than 5 feet. The bottom of the bed being under water at locations 33 and 34, it was impossible to ascertain the true thickness at either place. The variation in thickness of bed D from 2 feet 3 inches to 4 feet is clearly shown by sections 11, 12, 13, 45, and 46 on Plate III. The lignite beds in this vicinity are being mined at locations 11, 12, and 13.

In addition to the surface exposures, lignite is reported to have been discovered in wells at several localities in this township. For example, 2 feet of good lignite is reported in the log of a well near location 46. According to another report 9 feet of lignite occurs at a depth of 10 feet in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 26. Its elevation is about 2,090 feet, or 24 feet below that of bed B at location 48, in sec. 26, so that the lignite as reported may represent bed A. A lignite bed from 3 to 4 feet thick is reported to occur in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ of the same section. A 7-foot bed of lignite is said to have been found at a depth of 35 feet in the SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 14.

T. 139 N., R. 85 W.

The south half of T. 139 N., R. 85 W., includes a portion of the gently rolling upland between the valley of Big Muddy Creek and that of Sweetbriar Creek, and hence the southeast quarter of the township drains into Sweetbriar Creek, and the southwest quarter into the Big Muddy. The main line of the Northern Pacific Railway crosses the township in an east-west direction a short distance south of its middle line. New Salem, an enterprising town which is situated on the railway almost exactly in the center of the township, affords a market and shipping point for the surrounding territory. The south half of the township is occupied throughout by the lignite-bearing Fort Union formation. The few exposures of lignite observed during the geologic mapping are believed to represent only two beds, which on the basis of their probable stratigraphic position are assumed to be beds D and E. The lignite sections measured on the upper bed, or bed E, which has a maximum thickness of over 5 feet, are represented graphically on Plate III under Nos. 8, 9, and 10. Location 9, near the south line of sec. 21, marks an old abandoned mine. Considerable lignite was at one time mined here, but of late years the drift has been allowed to become partly filled with water. The lignite bed is overlain by 8 inches of black carbonaceous shale beneath a bed of sandy clay. Between the roof and the water there is 5 feet 4 inches of lignite. The extent of the lignite below the water could not be determined, but as the water does not cover the rails and in all probability the rails were laid on the floor of the bed the thickness of the bed is but little more than that given above. South of location 9 this bed is represented by a number of red "burns" almost to the northwest corner of sec. 33. The bed appears to get thinner toward the south, for at location 8, in sec. 33, it is only 2 feet thick.

The lower bed (bed D) at location 14 is 22 feet lower than the upper bed at location 8. The bed is about 5 feet thick. The details of the measurement made are shown on Plate III. At location 15,

in sec. 21, the bed contains 3 feet of lignite, but the top of the bed is not well defined owing to an admixture of sand and clay.

The section measured at location 10, in sec. 34, shows two separate benches of lignite separated by $2\frac{1}{2}$ inches of black carbonaceous shale. For convenience of classification this bed was correlated with the upper bed (bed E) on the west side of the divide, but owing to the local dips observed in the township immediately south the correlation is very uncertain.

The mouth of the main slope (Pl. IV, A) of the Dakota Products Co.'s mine is at location 64, about half a mile northeast of New Salem. The mine consists of a slope which goes down from the surface in a direction a few degrees south of west for a distance of nearly 200 feet. From the lower end of the slope the main haulageway is reported to run about N. 20° W. for a distance of 2,900 feet. The air shaft was sunk 2,500 feet from the lower end of the slope. Throughout this distance the bed has been mined out on either side for a considerable distance back from the main haulageway. At the time of visit, however, the mining was confined to an area from 200 to 400 feet north and west of the air shaft. The lignite bed where it has been mined ranges in thickness from 4 feet 6 inches to 6 feet. The analysis of a sample taken about 2,540 feet N. 20° W. of the mouth of the mine is shown under laboratory No. 20033 on page 17. At the point of sampling the bed consists of two benches separated by 4 inches of bone. The upper bench has a thickness of over 1 foot 4 inches, and the lower bench a thickness of 3 feet 1 inch. The sample represents the two benches of lignite. The lignite at the point of sampling is underlain by gray clay shale. The roof is reported to be very irregular, varying from clay shale to sandstone, and vice versa, in passing from one room to another in the mine. Though a rather pronounced north to west dip was reported for the mine in general, yet in places a local easterly dip was observed. As a result of borings made at intervals of 250 feet the lignite bed is reported as thickening toward the northwest.

Two other lignite beds are reported to occur below the bed which was being mined at the time of this investigation. The upper bed is said to have a thickness of 6 feet and to lie 121 feet below the surface. The lower bed is reported to have a thickness of 15 feet and to lie at a depth of 212 feet. The lignite bed then being mined is only 16 feet lower than the bed exposed at the old mine at location 9, in sec. 21. In view of the general northerly dip in the mine and the small difference in elevation between the two places mentioned, it is highly probable that the beds are either the same or very near together stratigraphically. There being no exposures of bed E north of location 10, in sec. 34, the position of the outcrop of the bed as mapped

was determined on the assumption that the lignite bed that was being mined is bed E.

In the autumn of 1919, according to a report by A. J. Collier, of the United States Geological Survey, the Dakota Products Co.'s mine had been abandoned and all equipment removed. Before the property was abandoned, however, a shaft was sunk to a depth of 235 feet in search of beds below the one formerly mined, and a bed of lignite is reported to have been found at the bottom of this shaft, consisting of 7 feet of "black jack" or carbonaceous shale and 2 feet of clay overlying 9 feet of lignite. Northwest of New Salem, in the SW. $\frac{1}{4}$ sec. 7, the Consolidated Lignite Collieries Co. was opening a mine on an 8-foot bed of clear lignite which probably can be correlated with that formerly mined near New Salem. The following section, based on information gained in sinking an air shaft above the 8-foot bed and a well near its outcrop, was reported by Charles Westmark, the mine foreman:

Section of lignite beds in sec. 7, T. 139 N., R. 85 W., northwest of New Salem.

Sand.	Ft. in.
Lignite-----	9 6
Clay-----	20
Lignite, bed mined-----	8
Clay-----	60±
Clay and sand-----	170
Clay-----	10
Lignite, "solid coal" (bed A?)-----	19
Clay.	
	296±

T. 137 N., R. 86 W.

T. 137 N., 86 W., occupies a portion of the divide between Big Muddy Creek and Heart River. Most of the western part of this township is a moderately high rolling prairie which is well settled and adapted to general farming. Almont, a station on the main line of the Northern Pacific Railway about three-quarters of a mile north of the north line of the township, is accessible by means of a fairly complete system of wagon rods and affords favorable market facilities.

Erosion has not advanced far enough to expose the Lance formation in a very large area, so that the Fort Union or lignite-bearing formation underlies almost the entire township.

The best bed of lignite observed in this township is exposed in secs. 5 and 6. From all appearances, however, the bed is lenticular. The details of the several measurements made on the bed are represented graphically under section Nos. 1, 2, 3, and 6, of Plate III. Location 2 marks the position of the Ramsland open-pit mine. The lignite bed was sampled at that point, and the results of the analysis

are shown under laboratory No. 19786 in the table on page 17. Where the bed was sampled it measured 6 feet 9½ inches, which included a 4½-inch bench of brown shale 10 inches from the bottom. A very pronounced northerly dip of 2 to 3 feet in 100 feet was observed in the bed where the overburden had been removed. At location 3, a few hundred feet to the northeast, the same bed has a total thickness of 6 feet 11 inches. The lower 12 inches of the bed contains many thin streaks of impure lignite, and this is separated from the main bed by 6 inches of sandy carbonaceous shale. The strata are well exposed at location 1, in sec. 7, and from all appearances the 14-inch bed there exposed represents the bed worked in the Ramsland mine. If it does, the bed not only thins rapidly but rises 46 feet in passing from location 2 to location 1. The lignite bed represented by the sections given above is correlated from its stratigraphic position with bed E as mapped farther north and east.

Location 43, in sec. 25, marks an exposure on a lignite bed which was correlated with bed A on account of its close proximity to the base of the Fort Union formation. At this location the bed measures 1 foot 10½ inches and has a ½-inch parting 4 inches from the top. Bed B in this township is thin and has a characteristic fossil bed immediately above it. Although the lignite varies in thickness only from 3 to 7 inches, the bed was traversed throughout the township for the purpose of determining the dip of the rocks.

T. 138 N., R. 86 W.

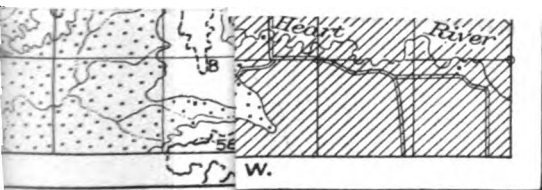
Unlike many of the other townships in this field, T. 138 N., R. 86 W., includes a large area of low valley land. The drainage either empties directly into Big Muddy Creek or enters it through its principal tributary near the township line, in the SE. ¼ sec. 35. Some of the most fertile soil occurs on the alluvium of the principal streams. The township is fairly well settled, and the inhabitants have the advantage of unusual market and shipping facilities. The main line of the Northern Pacific Railway, after leaving New Salem, swings south and follows the valley of Little Muddy Creek almost to the south line of this township. It then enters the valley of Big Muddy Creek and continues its northwesterly course. Sims, for some time a thriving lignite-mining town and a source of supply for the railway, is in the northern part of sec. 14. Almont, another shipping point, is in the NW. ¼ sec. 35. This township is occupied throughout by the lignite-bearing Fort Union formation.

A rather valuable bed of lignite has been uncovered at locations 4 and 5, in the SE. ¼ sec. 31. At location 4 about 10 feet of sandy shale has been removed, exposing the bed throughout an area about 75 feet wide and 250 feet long. The basin formed by the removal of the lignite was partly filled with water. Six feet of lignite was

exposed, but the amount of the bed below the water could not be ascertained. At location 5, on the north side of the valley, the lignite has been uncovered and mined throughout an area about 100 feet wide and 250 feet long. At one point in the open pit the lignite bed was found to have a thickness of 9 feet 4 inches. These two sections are represented on Plate III. This same bed was measured at locations 1, 2, and 3, in secs. 6 and 7, T. 137 N., R. 86 W., and is described in the section on that township. The "burns" shown in secs. 29, 30, 32, and 33 of this township are believed to represent this same bed of lignite burned on the outcrop.

The principal commercial development of lignite in the township is in the vicinity of Sims. For a time considerable lignite was mined at Sims by the Northern Pacific Railway Co., but of late years the supply of higher-grade coals farther west has caused the abandonment of the lignite as a fuel, so at present most of the old openings are badly caved and partly filled with water. The correlation of the lignite beds in the vicinity of Sims with those of the township to the east is very difficult, owing to the lack of exposures and the rather unusual dips observed in secs. 4, 5, 6, and 8 of that township. It seems probable, however, that the lignite bed exposed at location 18, in sec. 23, and also at the two old mine openings on the opposite side of the valley is bed B. This bed, as shown on Plate III, consists of two benches, an upper bench containing 2 feet 4 inches and a lower bench containing 3 feet 5 inches of lignite, but both benches are broken by shale partings so that they are not particularly promising. It was impossible to measure the bed at either of the old mine openings east of location 18. It is reported, however, that in the process of mining a 4-foot bed of lignite was cut some distance above the mined bed. The log of a deep well drilled at Sims,¹⁷ as given from memory by the driller, shows three "coal" beds having thicknesses of 8 feet, 5 feet, and 5 feet, respectively, within a depth of 130 feet. It also shows a 5-foot bed at a depth of 330 feet and a 6-foot bed at a depth of 710 feet. The writer is not inclined to place much dependence on such a well log, for two reasons—the log was reported from memory, and it is difficult, in a well boring, to distinguish between good lignite and impure lignite or even black carbonaceous shale. As the lignite beds in this field are very lenticular, it may be that there is at Sims an unusual development of lignite near the base of the Fort Union formation. However, as there is some doubt regarding the dips, the lignite bed at location 18, in sec. 23, might represent either bed A, B, or C. It is suggested that the reported 5-foot bed of lignite at a depth of 330 feet may be in the lower Lance, at or near the

¹⁷ Darton, N. H., Preliminary report on artesian water in a portion of the Dakotas: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 662-669, 1896.



Geology by E.T. Hancock

TON COUNTY
OF MEASURED &

horizon of the lignite mined on Little Heart River in T. 137 N., R. 81 W., south of Mandan.¹⁸

A lignite bed believed to be bed C was measured at the old mine at location 36, in sec. 12, where it consists of three separate benches, as shown in Plate III. Near the northeast corner of sec. 11, however, the same bed contains only 1 foot 5 inches of good lignite overlain by 7 inches of lignitic shale and underlain by gray clay shale. What appeared to be the same bed was noted at location 37, in sec. 3, and found, as shown on Plate III, to contain 3 feet 1 inch of good lignite.

Lignite was noted at other places in the township, but generally the beds are thin and do not promise to be of much value. An 18-inch bed of lignite caps the small hill in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 33. Two thin beds of lignite were measured in the buttes at locations 6 and 7, in the NW. $\frac{1}{4}$ sec. 22. At location 6 the beds are separated by an interval of 21 feet and the lower bed measures 2 feet 3 inches and the upper 1 foot 4 inches. At location 7 the lower bed contains 2 feet 1 inch of lignite, but the upper bed has thickened to 3 feet 5 inches. The log of a well near the house in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 22 reports 3 feet of lignite. The 19 inches of lignite exposed on the north slope in the SE. $\frac{1}{4}$ sec. 9 in all probability represents one of the beds noted above. A prominent "burn" about 45 feet stratigraphically below this bed seems to occur at about the same horizon as an 18-inch bed of lignite measured in the east bank of the creek in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 4.

¹⁸ Leonard, A. G., U. S. Geol. Survey Geol. Atlas, Bismarck folio (No. 181), p. 6, 1912.



DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 726—B

**GEOLOGY OF THE CEMENT OIL FIELD
CADDO COUNTY, OKLAHOMA**

BY

FRANK REEVES

Prepared in cooperation with the Office of Indian Affairs

**Contributions to economic geology, 1920, Part II
(Pages 41-85)**

Published August 10, 1921



**WASHINGTON
GOVERNMENT PRINTING OFFICE
1921**

CONTENTS.

	Page.
Introduction.....	41
Geography.....	42
General features.....	42
Topography of Kiowa area.....	43
Topography of Cement area.....	43
Drainage.....	44
Soil.....	44
Climate.....	44
Settlements.....	44
Roads.....	45
Geologic history of the region.....	45
Stratigraphy.....	45
Exposed rocks.....	47
General description.....	47
Greer formation.....	48
Cyril gypsum member.....	48
Woodward formation.....	51
Whitehorse sandstone member.....	51
Occurrence and general character.....	51
Thickness.....	51
Cross-bedding.....	52
Material and color.....	54
Changes in appearance of Whitehorse sandstone in Cement anticlinal area.....	54
Unexposed rocks.....	56
Base of the Permian.....	57
Origin of Permian "Red Beds".....	58
Origin of cross-bedding of Whitehorse sandstone.....	59
Structure.....	61
Relation of structure to the accumulation of oil.....	61
Key rocks.....	62
Structure of Cement area.....	63
Cement anticline.....	63
Cyril syncline.....	65
Cobb syncline.....	66
Structure of the Kiowa area.....	68
Relation of structure to topography.....	69
Development of Cement oil field.....	71
History of development.....	71
Oil sands.....	71
Caddo oil sand.....	72
Fortuna oil sand.....	72
Prosperity oil sand.....	72
Discovery of new sands.....	72
Production of wells.....	73
Extent of the field.....	73

Development of Cement oil field—Continued.	Page.
Grade of oil.....	74
Recommendations as to future development.....	75
Possibility of finding oil outside of the Cement field.....	76
Well tables.....	77

ILLUSTRATION

	Page.
PLATE VI. Geologic map of Oklahoma showing oil and gas fields.....	42
VII. Erosion features of Cyril gypsum and Whitehorse sandstone.....	48
VIII. Erosion features of Cyril gypsum and Whitehorse sandstone.....	49
IX. Cross-bedding in Whitehorse sandstone.....	60
X. Plotted logs of 11 wells in Cement oil field, Caddo County, Okla.....	72
XI. Structural map of Cement oil field and surrounding territory, Caddo County, Okla.....	In pocket.
XII. Structural map of Kiowa area, Caddo County, Okla.....	In pocket.
FIGURE 5. Generalized section of Permian "Red Beds" of Oklahoma.....	46
6. Rocks exposed in Cement oil field, Caddo County, Okla.....	47
7. Approximate boundary between marine and nonmarine sediments of basal Permian and upper Pennsylvanian in Kansas, Oklahoma, and Texas.....	59
8. Map showing absence of relation of ridges to structure and other features in Cement oil field, Caddo County, Okla.....	70

GEOLOGY OF THE CEMENT OIL FIELD, CADDO COUNTY, OKLAHOMA.

By **FRANK REEVES.**

INTRODUCTION.

The area discussed in this report is in Caddo County, in the southwestern part of Oklahoma, in the drainage basin of Washita River, north of the Wichita Mountains. It comprises Tps. 7 and 8 N., Rs. 11 and 12 W., and Tps. 5 and 6 N., Rs. 9 and 10 W. Its location with reference to the producing fields of Oklahoma and to districts in the State that have been described in reports of the United States Geological Survey dealing with oil and gas is shown on Plate VI.

It has long been believed that the region of tilted strata which borders the Wichita Mountains should contain local anticlines favorable for the accumulation of oil and gas. The pronounced anticline at Cement and anticlinal folds at Lawton and to the south in Cotton County support this belief. The production of oil at Cement proves not only that the structure at that locality is of the type favorable for oil accumulation but that there are adequate reservoir beds and a source of petroleum. It therefore seemed important that a portion of the region north of the Wichita Mountains should be mapped to determine the possibility of working out the geologic structure of the whole region and incidentally to determine the presence or absence of favorable anticlinal structure in the area examined.

A further reason for the work was the fact that much of the land in Caddo and Kiowa counties is owned by the Kiowa, Wichita, Caddo, and Apache Indians. Many tracts of the Indian lands are leased to oil companies every year, and it appeared highly desirable that geologic reports should be made available covering areas in which particular interest had been shown, in order that both prospective lessees and the Office of Indian Affairs, which administers the Indian lands, might form some idea of the true value of oil rights.

The field work that yielded the results incorporated in this bulletin was done by the writer, assisted by instrument men Edward F. Shea and Bruce White, during the five months beginning October, 1919. Mr. White also aided materially in the compilation of the report. The field work was done by plane-table methods. Locations and elevations were determined by direct or trigonometric leveling controlled by a system of triangulation.

As about half of the land examined belongs to the Indian tribes mentioned, financial cooperation was furnished by the Office of Indian Affairs.

For convenience in reference the northwest block of four townships is spoken of collectively as the Kiowa area, and the southeast block as the Cement area. T. 8 N., R. 12 W., is North Cobb Township; T. 7 N., R. 12 W., South Cobb; T. 8 N., R. 11 W., Grand View; T. 7 N., R. 11 W., West McKinley; T. 6 N., R. 10 W., Tonkawa; T. 5 N., R. 10 W., Doyle; T. 6 N., R. 9 W., North Cement; and T. 5 N., R. 9 W., South Cement. These townships are shown on figure 8 (p. 70).

ACKNOWLEDGMENTS.

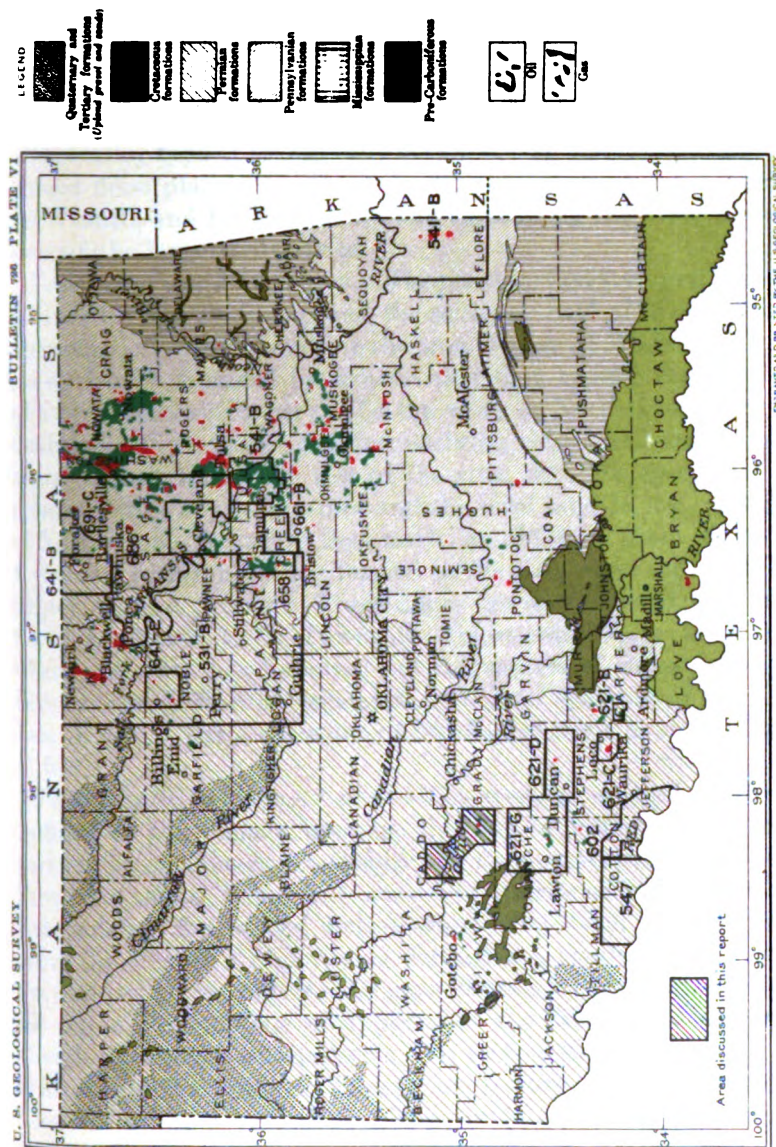
The writer wishes to express his appreciation of the courtesy shown and the aid given to him and his assistants in the progress of the field work by the farmers, oil men, and other inhabitants of the area. Thanks are due to Mr. C. V. Stinchecum, superintendent of the Kiowa Indian Agency at Anadarko, for cooperation and facilities furnished for the progress of the field work. The writer is also indebted to Mr. P. V. Roundy for examining the drill samples for paleontologic evidence of the age of the formations in which the oil sands occur; to Mr. R. C. Wells for his chemical study of the materials in the various colored phases of the Whitehorse sandstone, and to Mr. K. C. Heald, Mr. David White, and especially Mr. M. I. Goldman for the aid they furnished by suggestions and discussions with the writer of the geologic problems encountered.

GEOGRAPHY.

General features.—The area lies about 15 miles northeast of the Wichita Mountains, in the Permian "Red Beds" plain, which encircles the Wichita uplift and out of which the mountains rise "like islands in a sea." This plain in the area mapped has a relief of nearly 500 feet, for the highest point, on the top of the west end of the Keeche Hills, is 1,666 feet above sea level, and the lowest, the bed of Washita River where it flows out of the area, is but 1,170 feet above sea level.

The topographic features of the entire area can be classified in three groups—plain, sand hills, and valley bottoms.

The plain is a rolling treeless prairie deeply dissected by streams. It is underlain by a deposit of gypsum and in some places by limestone. The resistance of these beds to erosional forces has preserved the plain. The weathering of a higher gypsum bed has produced some prominent ridges on the surface of the plain. Along its borders and the stream courses the basal gypsum bed forms precipitous bluffs and rounded moundlike hills.



GEOLOGIC MAP OF OKLAHOMA SHOWING OIL AND GAS FIELDS

Heavy numbers refer to numbered bulletins in which other oil fields in Oklahoma are described

The sand hills occur where the plain has been destroyed by erosion. Their uneven, heavily wooded surface is underlain by soft red sandstone, which is usually covered with a soil formed of wind-blown sand. In many localities this sand in the past has been piled into dunes, but the movement of most of these dunes has now been arrested by vegetation.

The valley type of topography occurs where the major streams have formed flood plains. To this type belong the broad, level valleys of the Washita and Little Washita and those along the lower courses of some of the larger tributaries.

Topography of Kiowa area.—The plain surface forms upland slopes in Grand View Township and the southern half of West McKinley Township. These areas adjoin the broad valley of Washita River and are so deeply dissected by streams that they assume the appearance of a high plateau country. To the west, in North Cobb and South Cobb townships, there are a few outlying ridges that represent remnants of the plain. The rest of the area, with the exception of the present valley of the Washita and the level land in the central part of North Cobb Township that marks an old flood plain of the river, is covered with sand dunes formed in the past when the rainfall was lighter than at present. These dunes are now covered with vegetation. In North Cobb Township "blow-outs" have been formed where the wind has hollowed out the centers of dunes, whose tops have become barren of vegetation. A good example of these blow-outs, in sec. 7, has a diameter of 250 feet at the rim and a depth of 45 feet.

Topography of Cement area.—The most prominent topographic features of the Cement area are the Keeche Hills, in the northern part of South Cement Township and the southeastern part of Tonkawa Township. These hills consist of a series of barren rock ridges and isolated flat-topped buttes which rise from 100 to 200 feet above the crest of a high divide, formed as a result of the arching of the plain surface, and are the most prominent landscape feature of the region, resembling in appearance the Wichita Mountains, although on a much smaller scale. In fact, with the exception of the Wichita uplift there is no topographic feature in southwestern Oklahoma to compare with them. The divide on which they are situated continues northwestward through the southern part of Tonkawa Township. The south flank of the divide slopes rather steeply to Little Washita River, on the south side of which there is a second less prominent ridge. Southeast of South Cement Township this sloping plain is replaced by sand hills. North of the divide the old plain surface has been largely removed, leaving only a few scattered ridges and outliers, and the area that it once covered now shows the

sand-hill type of topography. The slope on the north side of the divide continues to the valley of Washita River.

Drainage.—Washita River, which flows eastward across the Kiowa area, receives the drainage of the area mapped with the exception of the southwestern part of Doyle Township, which drains into Red River by way of Cache Creek. The valley of the Washita is 1 mile to 2 miles wide and contains a series of lakes that mark former positions of the meandering stream. About 15 feet above the present flood plain there is a broad terrace, which represents an earlier flood plain. At higher levels there are remnants of other terraces, whose surfaces are covered by beds of gravel composed of pebbles derived from igneous rocks. The river follows a very sinuous course and has formed great meanders, which are being entrenched owing either to an elevation or tilting of the region or else to an increase in volume of water in comparatively recent geologic time. The secondary streams that drain the area have numerous tributaries and deep, narrow canyons in the upland plain and few tributaries and broad valleys in the sand hills. Some of the major secondary streams flow in synclines, their position and direction of flow being determined by the geologic structure of the region. Among these are Cobb Creek, Deep Creek, and Little Washita River.

Soil.—The soil of the region outside of the area of wind-blown sand ranges from a heavy black loamy clay to a bright-red loam which makes good pasture land or fertile soil for agricultural crops. This area is not wooded, except along the banks and valleys of streams, where there are cottonwood, elm, post oak, bur oak, cedar, locust, box elder, walnut, and a few pecan trees. In the area of wind-blown sand the soil for a considerable depth is very sandy and fairly fertile. Except where the woods have been cleared off these sandy areas are commonly covered with a scrubby growth of blackjack oak. The principal crops are cotton, maize, wheat, corn, kafir corn, broom corn, and cane.

Climate.—The climate is mild and dry. The winters are moderate, with occasional light snowstorms and cold periods produced by cold north winds. The summers are very hot, but the heat is usually tempered by brisk winds. The annual rainfall, which averages about 35 inches, is extremely irregular. During some summers there is so little precipitation that nearly all vegetation dies. During summers of sufficient rainfall, large agricultural crops and abundant fruit and vegetables are raised.

Settlements.—There are four small villages in the area mapped. Cement has a population of 2,000, Fort Cobb 1,000, Cyril 600, and Washita 100. The rural districts are rather thickly settled, with a house on nearly every quarter section. The inhabitants are whites, Indians (Kiowa, Wichita, Caddo, and Apache), negroes, and Mexicans.

Roads.—County roads extend along most of the section lines and are fairly good, except the valley roads, which become almost impassable during rainy periods. The St. Louis-San Francisco and Chicago, Rock Island & Pacific railroads cross the area.

GEOLOGIC HISTORY OF THE REGION.

The area mapped lies on the border of the Wichita Mountain uplift, and its geologic history is closely associated with that of the mountain region. According to Taff,¹ these mountains were produced by intensive folding of igneous and sedimentary rocks by forces that acted from the northeast and southwest and that produced folds trending northwest. This folding occurred in two periods—the first at the end of Mississippian time and the second at the end of Pennsylvanian time. Each uplift was followed by periods of erosion, so that at present the mountains consist of a central elevated mass of igneous rocks, with steeply inclined Cambrian and Ordovician limestones forming minor parallel ridges along the sides. At the base of the mountains the almost horizontal Permian “Red Beds” overlie these older rocks, and it is therefore impossible to determine to what extent the Pennsylvanian and Mississippian rocks were removed by erosion before the “Red Beds” were deposited, but it is probable that the unconformity at the base of the Permian, though representing the removal of thousands of feet of strata in the central part of the uplift, is not continuous many miles away from this area. The unconformity at the base of the Pennsylvanian, however, is of wide extent. Since Pennsylvanian time there has been some folding along the former lines of uplift, which has bent the Permian strata into a low arch in the region between the Wichita and Arbuckle mountains and has also produced folding parallel to the mountains in the area mapped. The latter folding, as is set forth on page 50, probably was initiated at the beginning of Greer time and possibly renewed in a late geologic period, as indicated by the rejuvenation of the streams and the arching of the old plain surface.

STRATIGRAPHY.

The surface rocks of the Cement field and about 1,500 feet of the underlying beds are regarded by the writer as of Permian age. They consist of red and blue shales, red and gray sandstone, gypsum, and limestone. The classification of the Permian in Oklahoma shown in figure 5 was made by Gould.²

¹Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita mountains: U. S. Geol. Survey Prof. Paper 31, 1904.

²Gould, C. N., Geology and water resources of Oklahoma: U. S. Geol. Survey Water-Supply Paper 148, p. 40, 1905.

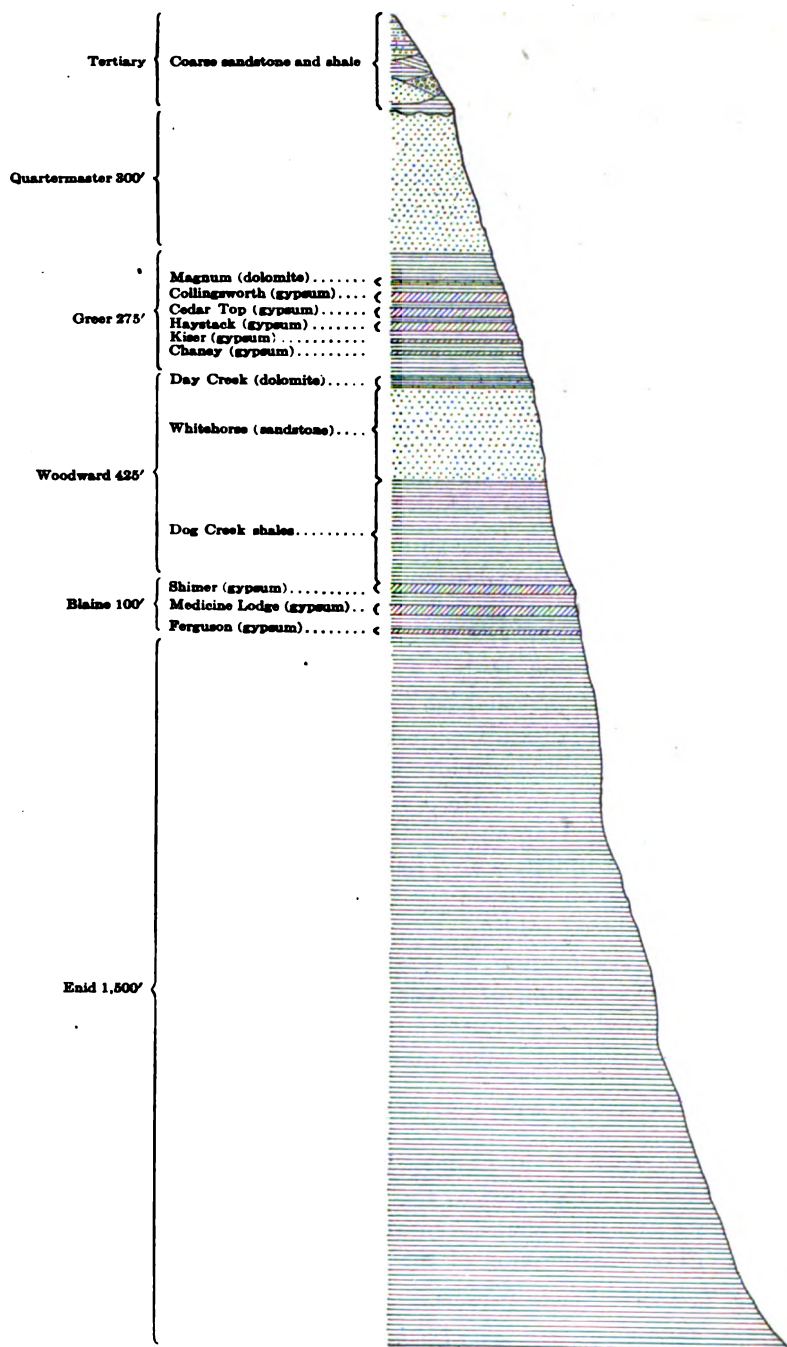


FIGURE 5.—Generalized section of Permian "Red Beds" of Oklahoma. After Gould.

EXPOSED ROCKS.

GENERAL DESCRIPTION.

The rocks that crop out in the Cement field belong to the Greer and Woodward formations and consist of the Whitehorse sandstone member of the Woodward formation, overlain by a thin limestone, 1 foot thick, representing the Day Creek dolomite member of the Woodward, which lies beneath a gypsum bed (Cyril gypsum) that belongs to the Greer formation (fig. 6, A). Clapp³ in a recent publication on the geology of the Cement field has made a different interpretation of the stratigraphy of the area (fig. 6, B), placing the gypsum deposit, which he named the Cyril gypsum, in the Blaine formation and the sandstone underlying it in the Enid formation. This sandstone, with the overlying gypsum, forms a continuous outcrop across the area mapped and connects with the red bluffs along

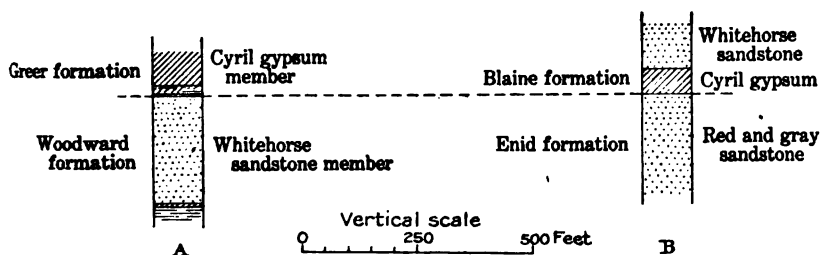


FIGURE 6.—Rocks exposed in Cement oil field, Caddo County, Okla. A, interpretation of stratigraphy outlined in this report; B, interpretation given by F. G. Clapp.

Washita River between Chickasha, Anadarko, and Mountain View. The Oklahoma Geological Survey correlates this sandstone with the Whitehorse sandstone member of the Woodward formation.⁴ The Cyril gypsum, which overlies this sandstone in an almost continuous outcrop, has been traced northwestward to the gypsum hills of western Washita County, which, according to the Oklahoma Geological Survey, belong to the Greer formation.⁵ In the northern part of the area mapped the lower bed of the Cyril gypsum is underlain by a thin limestone that has been traced northward and correlated with the Day Creek dolomite member of the Woodward formation in the northern part of Caddo County, where it caps a number of prominent buttes formed by a sandstone which Cragin⁶ identified as the Whitehorse sandstone.

³ Clapp, F. G., *Geology of Cement oil field*; Am. Inst. Min. and Met. Eng. Bull. 158, sec. 7, pp. 3-4, 1920.

⁴ Aurin, Fritz, *Geology of the "Red Beds" of Oklahoma*; Oklahoma Geol. Survey Bull. 30, p. 28, 1917.

⁵ Idem, p. 30.

⁶ Cragin, F. W. T., *The Permian system of Kansas*; Colorado Coll. Studies, vol. 6, p. 4, 1896.

Considering the great thickness of the Whitehorse sandstone and the fact that its outcrop has been mapped across the eight townships, the writer is certain that he has made no mistake in correlating the sandstone of the Cement section with the sandstones to the northwest which have been classified by previous writers as the Whitehorse sandstone.

GREER FORMATION.

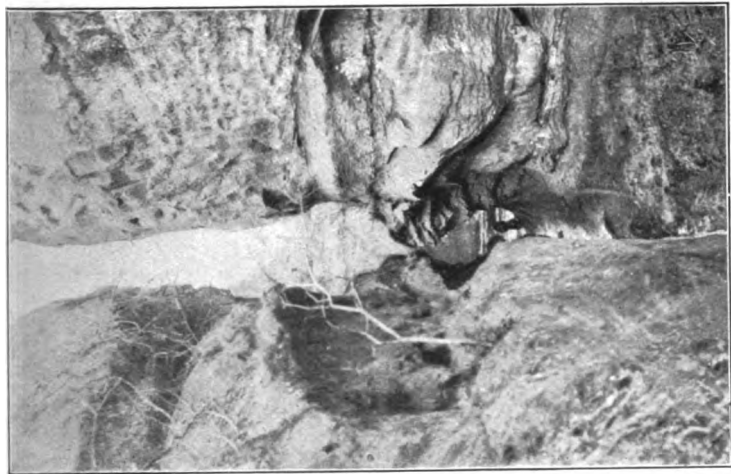
CYRIL GYPSUM MEMBER.

Only the basal part of the Greer formation is present in this area, where it is represented by the Cyril gypsum member.

The name Cyril was first applied to this gypsum by F. G. Clapp.⁷ In some parts of the area the Cyril member consists wholly of gypsum; in others it consists of two beds of gypsum separated by 15 to 20 feet of gypsiferous sandy shale. The upper gypsum bed has been eroded away except along the water divides, and here its top has been removed and the whole weathered into prominent ridges such as those seen south and west of the Keeche Hills; in secs. 32 and 33, West McKinley Township; secs. 8 and 9, Grand View Township; and sec. 13, T. 8 N., R. 13 W. (west of North Cobb). (See Pls. VII, VIII.) With the exception of some of the Keeche Hills the highest land in the region is formed by this bed. Its greatest thickness in the area is in sec. 32, Tonkawa Township, where it measures 85 feet. It consists of a massive bed of pink to white crystalline gypsum with scattered lentils of gray sandstone. As a key rock this upper bed is of almost no value, for the top has been removed by erosion and the base is generally not exposed except where the bed caps the buttes in the east end of the Keeche Hills. (See Pl. VIII, B.) There it rests directly on the Whitehorse sandstone, owing to an erosional unconformity, and has been altered to a limestone by the action of ascending ground waters.

The lower gypsum bed is 15 to 20 feet below the upper gypsum bed, being separated from it by gypsiferous shales. This lower bed supports the greater portion of the plain and forms the flat-topped surfaces on which, in scattered outliers, occur the ridges and hills of the upper gypsum bed. Its thickness ranges from 1 foot to 40 feet and increases toward the synclinal areas described under "Structure." In material it resembles the upper gypsum bed, except that in certain localities it is laminated and has the appearance of thin-bedded limestone. Its resistance to weathering and its position above the friable red Whitehorse sandstone result in the formation of prominent precipitous bluffs and canyon walls where it has been cut by running streams. Here and there the Whitehorse sandstone weathers out

⁷ Op. cit., pp. 3-5.



A.



B.

U. S. GEOLOGICAL SURVEY

BULLETIN 726 PLATE VIII



A.



B.

EROSION FEATURES OF CYRIL GYPSUM AND WHITEHORSE SANDSTONE.

from under it, leaving overhanging cliffs. Streams in many places have eroded channels under it, producing caves and natural bridges. (See Pl. VIII, A.) The outcrop of the bed is irregular and is locally concealed entirely by sand. The best exposures are those facing the southwest, owing to the uncovering action of the strong southwesterly winds which blow almost continuously during February and March. The land is covered in the fall and winter by a thick growth of broom weed, which is absent on the soil derived from the underlying Whitehorse sandstone, except in localities where this sandstone is gypsiferous.

The lower gypsum bed underlies about half of the Cement area and about one-quarter of the Kiowa area. In South Cement and Doyle townships it is prominently exposed, overlying the Whitehorse sandstone along streams. It also forms a continuous outcrop in the southern part of Tonkawa Township and scattered outliers in North Cement Township. In the Kiowa area a considerable portion of West McKinley Township is underlain by the same gypsum bed.

To the north and west, in Grand View, South Cobb, and North Cobb townships, the lower gypsum bed is absent, but the underlying thin limestone which caps the Whitehorse sandstone is present. This stratum is about a foot thick. On fresh fracture it varies in color from pink to black, the latter color being due to the presence of manganese dioxide. As a rule it is thinly laminated, and in places the lamination planes are folded, so that the rock has the appearance of fossil wood. The limestone weathers into thin platy fragments and forms at its outcrop a slight topographic bench. About 15 feet above this limestone, in the townships above mentioned, there are a few scattered outliers of the upper gypsum bed, the interval being occupied by gypsiferous sandstone and red shale. To the south the limestone is continuous, appearing as a thin band of calcareous material forming a sharp contact with the overlying gypsum and the underlying Whitehorse sandstone. Though of about the same thickness and chemical composition as in the areas where it is not overlain by the gypsum, it is usually softer and less commonly laminated and has a green or blue color, in places mottled black by the presence of dendritic crystals of manganese dioxide. This limestone stratum was traced north of the area and correlated with the Day Creek dolomite where it caps the Caddo County Buttes, southwest of Bridgeport. These buttes are haystack-like hills which have been eroded out of the Whitehorse sandstone. The lower gypsum bed is not seen overlying this limestone north of Washita River; in fact, south of the river, in the area mapped, its occurrence is confined to synclines. Up the flanks of the synclines it thins and gradually disappears.

In the Cement area the limestone is present up the flanks of the anticline, but in the two dome areas on the crest of the anticline it and the shales lying between the upper and lower gypsum are absent, and the Whitehorse sandstone buttes are capped with a thick, massive bed of gypsum which apparently is the upper bed of the Cyril gypsum. The contact between the two beds here is irregular and forms dips discordant to the apparent structural dips of the strata. Thus it appears that there is an unconformity here. This unconformity, together with the thinning and disappearance of the lower gypsum, suggests that in early Greer or late Woodward time the earth movements that resulted in the change in deposition of sand to gypsum produced some folding of the strata along the lines represented by the present structure of the region, with the formation of an inland basin. In the first stage of evaporation of the water in this basin carbonates were precipitated, forming the limestone bed beneath the Cyril gypsum. As folding and evaporation continued the water receded from the area of uplift marked by the Cement anticline, and, as a result, on the crests of the domes there was emergence and probably erosion. Along the flanks of the folds only limestone was deposited, indicating that the water withdrew from these areas before concentration had gone far enough for more than the precipitation of calcium carbonate from the water, while in the synclinal areas gypsum was deposited in increasing thickness as the water receded and occupied lower and lower levels in the central parts of the basin. Thus in the Cyril and Cobb synclines the lower gypsum bed attains a thickness of 35 and 20 feet, respectively, but gradually thins up the flanks of the folds. This thinning is uniform and conforms relatively in amount to the dip of the rocks.

The unconformity outlined above, though apparently of local extent, probably occurs in other regions where there have been crustal movements contemporaneous with those which produced the Cement fold. Beede^a reports a pronounced unconformity in Coke County, Tex., occurring at the base of the beds which he calls the San Angelo formation and correlates with the lowest part of the Double Mountain formation of the Texas Permian. The San Angelo formation of Beede underlies a series of shales and gypsum beds which Wrather^b correlates with the Greer formation of Oklahoma. Beede consequently refers the unconformity to the base of the Whitehorse sandstone.

^a Beede, J. W., Texas Univ. Bull. 1847, 1918.

^b Wrather, W. E., Notes on the Texas Permian: Southwestern Assoc. Petr. Geologists Bull. 1, p. 103, 1917.

WOODWARD FORMATION.

The only members of the Woodward formation exposed in the Cement area are the Whitehorse sandstone and the equivalent of the Day Creek dolomite member, represented by the thin limestone that underlies the lower bed of the Cyril gypsum.

WHITEHORSE SANDSTONE MEMBER.

OCCURRENCE AND GENERAL CHARACTER.

Except in the extreme southwest corner of South Cobb Township, the only rock below the Cyril gypsum that crops out in the area mapped is the Whitehorse sandstone. Except in the Cement uplift (fig. 8, p. 70) this rock is a friable reddish-brown cross-bedded to regular-bedded sandstone which weathers rapidly, producing a thick soil of sand that is blown about by the wind and in some localities piled up into sand dunes. Streams cut deep gorges in the sandstone, exposing it in the walls of narrow canyons. (See Pl. VII, A.) In places where it is capped by the Cyril gypsum or by an indurated layer of the sandstone itself, its outcrops form vertical bluffs along the edge of the upland plains of the region. The wind exposes it along the west sides of prominent ridges and erodes it into small conical mounds and barren slopes. The red color of these outcrops along the bluffs of Washita River and the valleys of many of its tributaries, such as Deep Creek, Stockton Canyon, Rock Creek, Tonkawa Creek, and the headwaters of Little Washita River, is a striking feature of the landscape. This same sandstone forms the famous Caddo County Buttes, in the northern part of Caddo County.

THICKNESS.

The thickness of the Whitehorse sandstone in the Kiowa area is not determinable. About 200 feet of it is exposed along the valley of Washita River near Fort Cobb, and there is nothing in the character of the lowest exposed sandstone to indicate that it lies at or near the base of the Whitehorse. The log of a well drilled in sec. 21, Grandview Township, shows 360 feet of "sandrock," but it is doubtful whether the Whitehorse sandstone is so thick. The logs of wells in the Cement area indicate that its thickness there is about 250 feet. At the base of the Whitehorse sandstone cliff which forms the river bluffs 1 mile north of the northeast corner of Tonkawa Township there occurs a 2-foot bed of white gypsum underlain by red gypsiferous shales. The interval between this gypsum bed, which apparently marks the base of the Whitehorse sandstone, and the top of the sandstone is 230 feet. This is probably the average thickness of the Whitehorse in the region. Toward the southern part of the area

mapped this sandstone thins rapidly or else shales replace its basal part, for in secs. 31 and 32, South Cobb Township, there are outcrops of red and green shales at a distance of about 100 feet below the top of the Whitehorse sandstone. However, as the upper portion of the sandstone becomes argillaceous toward the southwest in both the Kiowa and Cement areas, it is probable that the shales mentioned are a change in facies of the Whitehorse sandstone. These shales and the underlying Dog Creek shale constitute most of the outcropping rocks between the area mapped and the limestone hills bordering the Wichita Mountains and form the floor of the topographic basin which lies to the southwest of the ridge produced by the escarpment of the upper part of the Whitehorse sandstone and the overlying gypsum bed.

CROSS-BEDDING.

The bedding of the Whitehorse sandstone varies laterally and vertically from regular bedding to very pronounced cross-bedding. In a typical exposure of 100 feet of the sandstone there may be one or more layers of cross-bedded material, the remainder being regularly bedded. The regularly bedded portion usually has conspicuous bedding planes and consists of beds ranging from 1 to 30 feet in thickness and averaging about 10 feet. The thickness of the cross-bedded members ranges from 5 to 40 feet, and that of the oblique layers ranges from a fraction of an inch to 1 or 2 feet. On the truncated edges of these layers rests the overlying horizontal bed, producing the appearance of an unconformity. (See Pl. IX, A.) In some sections this condition is repeated two or three times, and in others at the same stratigraphic position the entire sandstone is horizontally bedded. In fact, none of the cross-bedded layers are continuous for more than a few thousand feet, and most of them probably extend only a few hundred feet. It is difficult to determine to what extent a cross-bedded layer is developed, for as a rule the outcrops are not continuous. Usually each outcrop shows different conditions of bedding from the others, even though it represents the same horizon of the sandstone.

The dips of the oblique laminae in cross-bedded layers are pronounced and resemble structural dips, for which they are sometimes taken by oil men. Of course these dips have no relation to structure, for they are not the result of folding of the rocks but are due to the manner of deposition, as is pointed out on page 59. Reference to Plate IX will clearly demonstrate that these dips are not structural dips. In Plate IX, A, the dip of the cross-bedded laminae is 28° in a direction 35° west of south. This is equivalent to a dip of 2,800 feet to the mile, while the true dip of the rocks is about that of the flat-lying bed shown in the photograph, or about 50 feet to the mile, and

in a direction 60° east of south, or about at right angles to the cross-bedding dips. In Plate IX, *B*, the dip of the cross-bedding is to the southwest at the rate of 3,050 feet to the mile, while the true dip as represented by the overlying gypsum bed is to the northeast at the rate of 40 feet to the mile. Plate IX, *C*, shows that the cross-bedding dips may incline in many directions in the same bed. Structural dips, in contrast to these, are parallel. In this region the strata dip so gently that it is difficult to detect the dips without instrumental work, but the cross-bedding dips are so steep as to be easily discernible. The cross-bedding dips may also be distinguished from the structural dips by noting the discordance between the inclination of the steeply dipping layers and that of contiguous beds. As shown in Plate IX, *A*, there is even a pronounced difference in inclination between beds that are in contact. A consideration of the dips of the cross-bedding, though of no value in determining the structure and oil possibilities of an area, gives valuable data from which to determine the origin of the sandstone, and to this end these dips will be considered further.

A regular and irregular type of cross-bedding in the Whitehorse sandstone can be distinguished. Typical examples of each of these are shown in Plate IX, the regular type in views *A* and *B* and the irregular type in *C*.

In the regular type of cross-bedding the oblique lamination planes are plane surfaces, and the dips at any one outcrop are all in one direction and all of approximately the same amount. The directions of these dips vary in different outcrops, but in the whole area mapped they are southward, with a range of 45° to the east or the west of south but usually a few degrees west of south. The angles of these dips range from 10° to 30° ; as a rule they are more than 20° . In the outcrop shown in Plate IX, *B*, the oblique lamination planes, which extend across a bed 40 feet thick, dip 30° . Only about 20 feet of the outcrop of this bed is exposed, so the total lateral extent of this cross-bedding is not known, but it is at least 20 feet. In the cross-bedded material shown in Plate IX, *A*, the dip is 28° and the bed is about 15 feet thick. The outcrop extends across a belt 300 feet wide and for a distance of 600 feet in the direction of the strike of the oblique laminae. Across this entire outcrop the strikes of these lamination planes are parallel and form straight lines. The horizontal length of the bed, measured at right angles to the strike, is at least 200 feet and probably much more. In another outcrop a cross-bedded layer 15 feet thick shows a length of 2,000 feet. Toward the base of a cross-bedded stratum the dip of the oblique laminae decreases and the layers thin and merge into the underlying horizontally bedded layers.

In the irregular type of cross-bedding the layers dip in every direction at angles ranging from a few degrees to 15° but rarely more than 10° . They comprise concentric and nonparallel layers, which are commonly less than an inch thick. The vertical extent of such cross-bedded material is usually less than 20 feet and its length not more than a few hundred feet. This type of cross-bedding is about as common as the regular type, and the two are found throughout the thickness of the Whitehorse sandstone. The origin of this type of cross-bedding is discussed on pages 59-61.

MATERIAL AND COLOR.

The homogeneous character of the Whitehorse sandstone is shown by the microscope to be due to a uniformity in the size of the grains of silica, the almost total absence of cementing materials, and the presence of a pigment of ferric oxide, which occurs as films and stains on the surfaces of the sand grains. Most of the grains are partly rounded, and their surfaces are smooth and glazed, probably as a result of wind action. The grains average 0.15 millimeter in diameter but range from 0.1 to 0.3 millimeter. The coloring material is apparently of secondary origin. It was probably added by ground waters and makes up about 1 per cent of the total material of the sand. It is evident that the coloring matter was not present in the grains before or during the deposition of the beds. Had it been there originally, it would apparently have been worn off by the rubbing induced by wind and water action, for the degree to which the materials have been sorted and the uniformity in the size of the grains indicate that they have been carried long distances and worked and reworked by water and wind. Apparently this sorting was so thorough that little more in this direction can be accomplished, for the sand grains in all types of bedding are very similar in shape and size.

CHANGES IN APPEARANCE OF WHITEHORSE SANDSTONE IN CEMENT ANTICLINAL AREA.

Toward the axis of the Cement anticline the brownish-red color of the Whitehorse sandstone that prevails in the rest of the area mapped changes abruptly to pink, white, and yellow. This change takes place about two-thirds the distance up the flanks of the anticline. The line marking the change, as shown in figure 8, closely parallels the structure contours, and the area inclosed by this line includes about twice the area of the closure of the fold. On the north and west flank of the anticline the color changes first from brownish red to pinkish white and then to yellow. On the south and east flank of the anticline the change is abrupt from brownish red to light yellow. The change can be seen along courses of streams in secs.

22 and 23, South Cement Township. A boundary line marking the change of color in a single outcrop is irregular in direction, at some places following stratification planes and at others cutting across the beds. This yellow color is continuous over the whole area of uplift except in the Keeche Hill buttes. In these buttes, which are on the highest part of the uplift, the Whitehorse sandstone is a hard gray calcareous rock, quite dissimilar in appearance to the soft yellow sandstone of other parts of the anticline and to the friable reddish-brown sandstone that occurs in areas outside of the uplift. The dissimilarity is so great that a few geologists have thought that the two sandstones belong to different formations or else that the change in color and composition was due to a change in the conditions of deposition. That the sandstone on the crest of the anticline and in these buttes is actually the Whitehorse is proved by outliers of the Cyril gypsum overlying it in some localities; by the structure indicated by well logs, which show that the dips are of a nature to carry the gypsum bed over the hills where it is now absent as a result of erosion; and by the fact that a microscopic examination of the sandstone shows that the sand grains are similar to those of the Whitehorse in other areas, the difference in appearance of the rock being due to the deposition of carbonates in its pore spaces, which outside of the area of uplift contain but little cementing material. That the change in the appearance of the sandstone is secondary and not the result of change in the conditions of deposition is indicated by the fact that it is limited to the area of uplift.

Apparently the alteration was induced by the folding of the rocks, and the agent that effected it was ground water. As the changes in color are due chiefly to addition of materials to the sandstone rather than subtraction, it is probable that the waters depositing these materials were ascending and not descending waters, for descending waters would have a leaching rather than a cementing effect on rocks lying near the surface, and besides there is no apparent reason why if a change of color were produced by descending waters in the anticlinal area a like change would not be produced in other areas, not anticlinal, which had a similar topographic relief, and there are in this region such areas in which no color change is present in the Whitehorse sandstone. On the other hand, ascending waters often effect near the surface a cementation of the rocks through which they pass. Such waters may be inferred to have been present as a result of the compression of the materials incident to the folding of the strata, the upward flow being confined to the area of greatest deformation—here the crest of the anticline—where fissures, joints, and fault planes would furnish channels along which the waters could move with comparative ease. These waters were probably rich in

carbonate solutions for, as Rogers¹⁰ points out, such solutions are characteristic of oil-field waters, and as these waters approached the surface a decrease of pressure and lowering of temperature would occur, with the result that carbonates would be deposited in the open-textured Whitehorse sandstone. Additional evidence of these ascending waters is seen in the cementation of the strata for considerable depths in the dome areas, where the drillers report that for several hundred feet the strata are much harder than elsewhere, and in the alteration of the upper Cyril gypsum bed in the same areas to a crystalline limestone, with the development of large crystals of calcite and aragonite.

With the gray color of the Whitehorse sandstone reasonably well explained, it is logical to infer that the ascending waters produced the other color changes, though the manner in which they effected these changes is not clear. The yellow phase may be due to the hydration of the red ferric oxide, and the pinkish-white color to the efflorescence of gypsum. They may, however, be due to the variation in the size of the color pigments, for Weiser¹¹ shows that the different colors of hydrous ferric oxide may be due to the variation in size of the colloidal particles.

Another tentative explanation for the upward movement of the water, offered by K. C. Heald, is as follows:

Buried peaks of hard rock may exist at no great depth beneath the domed areas, with large valleys filled with soft sediments on either side. The soft beds would tend to settle or slump toward the basins, and those over the basins would also lose more volume by compacting than those over the peaks. This would result in the formation of sharp domes over the buried hills or peaks, while extensive shear zones, developed through the slumping or settling of the beds in the marginal areas, would furnish ideal channels for the upward migration of the water, oil, and gas that were being squeezed out by the consolidation or "packing" of the beds, or that might escape from the unsealed edges of petroliferous formations unconformably below the barren capping of shales and sandstones. This would be particularly probable if the buried hills were anticlinal in structure. The migrating oil and gas would probably be arrested in porous beds before they had completed more than a fraction of the journey to the surface, but the water, with its greater facility for traversing openings of minute size, would continue to the surface, urged on by the pressure resulting from the compacting or squeezing of the beds.

UNEXPOSED ROCKS.

Beneath the Whitehorse sandstone, which is the lowest exposed rock in most of the area mapped, wells drilled in the Cement oil field (see Pl. X) have penetrated a total thickness of 3,640 feet of alternating

¹⁰ Rogers, G. S., The Sunset-Midway oil field, Calif., Part II: U. S. Geol. Survey Prof. Paper 117, p. 27, 1919.

¹¹ Weiser, H. B., Hydrous ferric oxide: Jour. Phys. Chem., vol. 24, No. 4, pp. 277-328, 1920.

beds of red and blue shale, sandstone, and limestone, of which blue shale forms an average of 41 per cent, red shale 31 per cent, sandstone 25 per cent, and limestone 3 per cent. These strata may be classified into four groups—a sandstone group, a red-shale group, an oil-sand group, and a lime-shale group. The percentages of the different rocks in each group are shown in the following table. The sandstone group forms approximately the first 900 feet of strata and is composed of upper and lower sandstones, separated by several beds of blue and red shale. The upper sandstone is the Whitehorse, and the lower probably belongs to the Blaine formation. The shales are apparently the Dog Creek shale member of the Woodward formation. The red-shale group comprises 600 feet of strata underlying the sandstone group and consists almost entirely of shales, two-thirds of which are red, but contains also a few lenticular sandstones. This group probably belongs to the Enid formation. Below the last thick bed of red shale there is about 900 feet of alternating red and blue shales and shaly sandstones and brown and gray lenticular sandstones. These sandstones form the oil sands of the Cement field. The rocks below this group have been penetrated by only three wells. They appear to be chiefly blue and red calcareous shales.

Percentages of different rocks in different groups of strata penetrated by wells in the Cement oil field, Oklahoma.

Group.	Thick- ness (feet).	Sand- stone.	Shale, blue.	Shale, red.	Lime- stone.
Sandstone.....	900	44.9	37.3	10.9	6.9
Red shale.....	600	5.9	33.0	60.0	1.1
Oil sand.....	900	18.9	43.3	33.8	4.0
Lime shale.....	800	2.4	63.9	30.8	2.9

BASE OF THE PERMIAN.

The thickness of the Permian in the Cement field is estimated by different geologists at 800 to 2,700 feet. Drill samples were collected from a number of wells and examined for fossils by P. V. Roundy, but only a few Foraminifera and sponge spicules were noted, and these were types that have so wide a geologic range that they were of no use in determining the age of the strata. An attempt was made to trace the formations eastward to the outcrop of the Pennsylvanian formation in northern Garvin County by the use of well logs. However, few wells have been drilled in the intervening area, and the correlation is only tentative. The conclusion based on this correlation is that the top of the Pennsylvanian is at a depth of about 1,500 feet, at the base of the red-shale group.

ORIGIN OF PERMIAN "RED BEDS."

There has been considerable discussion as to the manner of deposition and climatic conditions under which the Permian "Red Beds" of Kansas, Oklahoma, and Texas were deposited. Many geologists, among them Cope, Beede, and Wegemann, have considered that they represent sediments derived from the Arbuckle-Wichita mountain uplift and deposited in shallow terrestrial water or on tidal flats of deltas, but in view of the high degree of sorting and the fineness of the Whitehorse sandstone, which shows no change in the character of material up to its last outcrop 10 miles from the crest of the mountains, and the fact that the direction of the regular type of the cross-bedding indicates that the currents which produced it were not from the Wichita Mountains but from the north, it seems improbable that the Whitehorse sandstone or any of the Permian to the north of the mountains, except local talus slopes and conglomerates directly adjacent to the mountains, had such an origin. On the other hand, it seems reasonable to consider the whole of the later Carboniferous as a delta deposit which was built up eastward in the Pennsylvanian and Permian seas over approximately what is now western and central Oklahoma. The rivers that rose in late Carboniferous time from land masses in the region now occupied by the Rocky Mountains deposited over the flood plains of the subaerial portion of this delta the continental sediments that make up the "Red Beds," while in the sea to the north, east, and south the marine sediments into which the "Red Beds" merge were being laid down. Thus, to the south the nonmarine deposits of the Wichita formation are replaced by marine deposits south of Salt Fork River in Texas. To the north the continental "Red Beds" of the Permian grade into the marine sediments of the Sumner and Chase groups of Kansas, and to the east the upper Pennsylvanian "Red Beds" merge into gray and blue marine sediments, the marine Permian in that direction having been removed by erosion.

The line marking the boundary between the marine and non-marine facies of the basal Permian and upper Pennsylvanian (see fig. 7) forms a broad curve to the east across central Oklahoma, which suggests that the delta was built outward into a sea in this direction and that its shore line in early Permian time conformed approximately to the line indicated. During the growth of the delta there would be a shifting of the strand line, bringing about an intercalation of marine and nonmarine sediments. In some of the lagoons in the subaerial portions of the delta swamp deposits would be formed, while in others gypsum would be deposited. Parts of the flood plain would be alternately flooded and exposed to the action of the wind. Thus, in a general way, all the conditions of sedimentation represented in the Permian strata would have been developed.

ORIGIN OF CROSS-BEDDING OF WHITEHORSE SANDSTONE.

Considering the possibility of the delta origin of the Permian "Red Beds," it is thought that the conditions of deposition producing the types of bedding of the Whitehorse sandstone could have been brought about if to the south of the area under discussion the delta was built out into an inland body of water instead of into an open sea. The

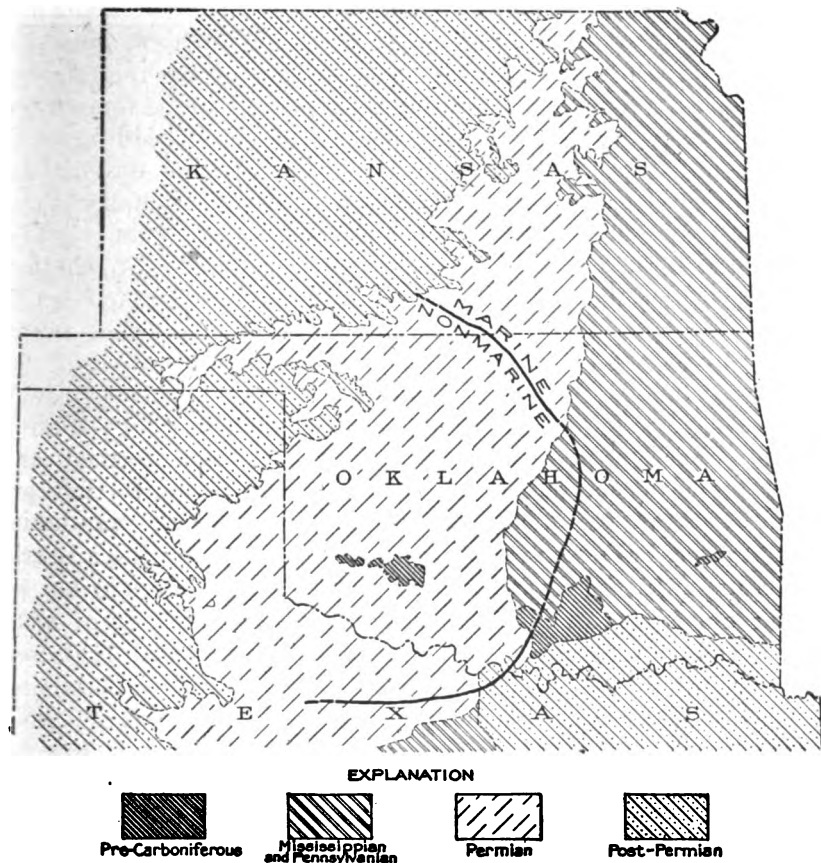


FIGURE 7.—Approximate boundary between marine and nonmarine sediments of basal Permian and upper Pennsylvanian in Kansas, Oklahoma, and Texas.

regular type of cross-bedding described on page 52 and shown on Plate IX, A and B, apparently was formed in a standing body of water, for it is inconceivable that cross-bedding with foreset slopes so long, dipping at angles so high and so uniformly in one direction, could have been formed in stream channels or on the flood plain of a river. That this type of cross-bedding is not that of the foreset beds of a marine delta is indicated by the facts that these beds are not continuous horizontally for more than a few hundred feet and that

they are confined to no definite bed but may occur at several horizons in a single outcrop lying between horizontally bedded strata. Such delta foreset beds indicate a fluctuation in the level of the body of water that received the sediments. As Grabau¹² points out, such a fluctuation could scarcely occur on a subsiding seacoast like those on which most deltas are formed, but it could readily occur on an inland body of water as a result of slight climatic changes. If such a body of water had been present along the southern edge of the delta the various types of bedding noted in the Whitehorse sandstone would have been developed, the cross-bedding of the regular type being formed by streams depositing their load of silt as foreset beds as they flowed into this body of water and the cross-bedding of the irregular type being produced by the wind drifting the material about on the subaerial portion of the delta. The horizontally bedded strata were probably deposited when the body of water due to floods or a decrease in evaporation advanced over the flood-plain flats. That such a body of water existed is not only suggested by the types of cross-bedding, but it is indicated by the fact that toward the south the Whitehorse sandstone becomes argillaceous and contains considerable gypsum as cementing material, whereas toward the north it is a quartz sand containing but little gypsum as cement. Such a body of water could have been formed as a result of movements along the Arbuckle-Wichita uplift that produced a narrow bay along the northeast flank of the mountains. This bay may have been cut off by the delta river throwing a barrier across its outlet, in about the same way that the Colorado has cut off the upper part of the Gulf of California. This body of water may have been the source of the gypsum beds which were laid down at the end of Whitehorse time over wide areas in western Oklahoma.

The absence of any evidence of vegetation in the Whitehorse sandstone, together with the aridity suggested by the deposition of gypsum at the beginning and end of the Whitehorse epoch and the occurrence of eolian cross-bedding, suggests that the flood plain of the delta in the area under discussion lay in an arid belt. The fact that the Whitehorse sandstone contains no alluvium, such as is usually characteristic of flood-plain deposits, and the well-sorted, glazed, and rounded character of the sand grains indicate that the material had been worked over by winds, which apparently removed the finer argillaceous material, drifting it probably toward the northeast, in the same direction that the present southeasterly winds carry the flood-plain material of the rivers of the area. This aridity may have been a widespread climatic condition during Permian time, or it may have prevailed only in a local belt, owing

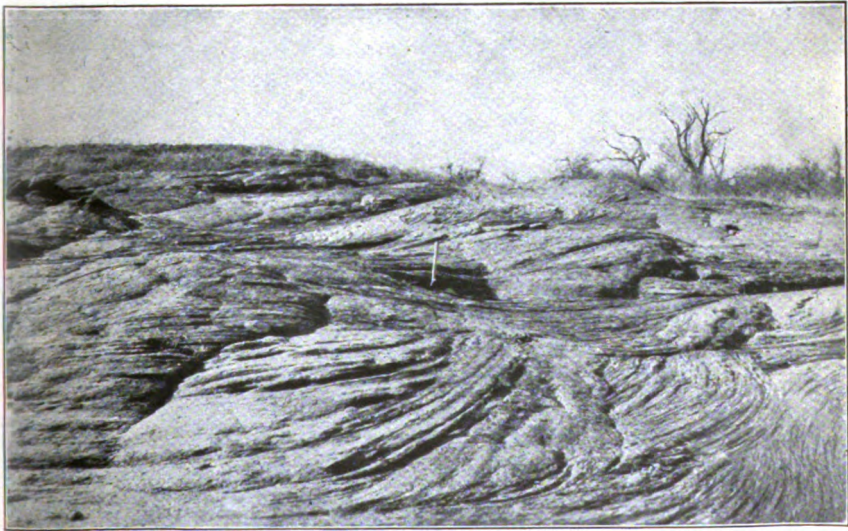
¹² Grabau, A. W., *Principles of stratigraphy*, p. 702, 1913.



A.



B.



C.

CROSS-BEDDING IN WHITEHORSE SANDSTONE.

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to the fact that the flood plain here lay to the leeward side of the Wichita Mountains and another mountain mass which probably existed at that time in the present Rocky Mountain region. This region is now more arid than surrounding regions. Similar conditions of sand deposition over a flood plain are exemplified at the present time by the desert flood-plain area of the Nile.

Evidence of stream channeling, which would be expected to occur in the Whitehorse sandstone if it had the origin above outlined, was not observed in this area, but it is thought that only the minor delta distributaries of the delta river flowed across the area. Probably not one of the minor streams would hold to one course long enough to leave much evidence of its position. The main delta river is thought to have lain to the north, probably in the present central part of Oklahoma, and to have flowed eastward or southeastward into the open sea. Dr. C. N. Gould called the writer's attention to a stream channel which lies a few miles northeast of the area studied. This channel can be traced 30 miles or more in a southeasterly direction from a point 3 miles northwest of Verden, in Caddo County. It is marked by a bed of hard, coarse-grained lenticular sandstone containing marine fossils, which fills the old channel and weathers into a series of ridges that extends across the country, marking plainly the course of the ancient stream. (See Pl. VII, B, p. 51.) The greatest thickness of the sandstone is about 10 feet, and its greatest width about 1,000 feet, indicating the approximate cross section of the lower part of the stream. Apparently the stream meandered but slightly. In the 25 miles that this channel was traced it showed but the slightest variation from a direction of S. 45° E. The channel was apparently formed early in Whitehorse time, as it is confined to a horizon approximately 200 feet below the top of the Whitehorse sandstone. The channel sandstone is cross-bedded, with dips to the northwest, and is very dissimilar in texture to the fine-grained Whitehorse sandstone at this horizon, which, where cross-bedded, has dips in the opposite direction. The presence of small marine shells and the apparent "upstream" cross-bedding suggest that a strong tidal current flowed up this stream from the sea.

STRUCTURE.

RELATION OF STRUCTURE TO THE ACCUMULATION OF OIL.

The Cement field offers an ideal illustration demonstrating so definitely and clearly that geologic structure plays a part in the accumulation of oil that even those who have no knowledge of the meaning of geologic structure or who do not believe that it is a factor in the accumulation of oil can not fail to recognize the fact.

Geologic structure is a term used to describe the attitude of rock layers of the earth's crust that have been folded or otherwise moved from the horizontal or nearly horizontal position in which they were deposited. Folding of rock beds is almost universal. In some regions the rocks are bent steeply upward into high arches that may produce mountains or other prominent topographic forms. In many regions, however, among them the area described in this report, the folding is very gentle, the strata being thrown into a series of mild upward and downward flexures. These upward folds are called anticlines or domes, and the downward folds synclines. If the rocks in beds so folded are sedimentary—that is, if they originated from muds, sands, slimes, and other loose materials carried by wind, water, and other surface agencies—and if they contain buried organic matter, remains of plants and animals that lived during the period in which the beds were being deposited, and also include porous rocks such as sandstones lying between compact-textured rocks such as shales, then the conditions are present for the accumulation of the hydrocarbon known as petroleum. Under such conditions the organic matter buried in the rock may be converted into petroleum during the geologic ages that follow the deposition, and, through the forces of capillary action and the consolidation of the sediments, as the writer believes, this petroleum is forced out of the shales into the porous sandstones. If these sandstones contain water, these liquid hydrocarbons ultimately, through forces that are not perfectly understood, reach the top or a position high on the flanks of the folds, and there they remain under pressure developed mainly by the expansive force of the gas generated in the petroleum itself. This briefly explains why oil is usually found in anticlines.

KEY ROCKS.

It is apparent that the folding of the rocks is but one of several factors affecting accumulation, but without folding the oil present in the strata will usually not be segregated into pools of sufficient size to repay the cost of drilling to obtain it, though shows of oil may be widely encountered. Folding, of course, will not effect accumulation unless the other factors are present; hence not every anticline yields oil. An important part of the work of the oil geologist, therefore, is the determination of the structure, for from his knowledge of the rocks that underlie the surface in an area, obtained from a study of their outcrops in adjoining regions or from the study of well logs, he knows whether they are by nature of material favorable for the accumulation of petroleum. In order to determine the structure he must ascertain the dips of the beds over a considerable area. Where the rocks are sharply folded these dips can be determined

simply by a clinometer, which works on the principle of a plumb bob and shows the amount by which the dip of the rocks differs from the vertical or horizontal. However, where the beds are gently folded, as in most parts of the Mid-Continent field, the attitude of the rocks is ascertained by determining a great number of elevations on one or more persistent beds that can be identified and traced over the area. Good beds for this purpose are thin limestones or hard sandstones or beds of coal or gypsum. A stratum used in this way is called a key rock. The elevations taken on these key rocks are all reduced to terms of the elevation of one datum plane, by adding or subtracting from each elevation determined the vertical distance that the bed on which it was taken lies above or below the selected datum plane. When the elevations have all been thus reduced points that show the same elevation are connected by lines called contour lines. These lines show the direction along which the strata lie horizontal. Such a direction is known as the strike of the rocks. The dip is at right angles to these lines and in the direction of the slope of the strata. In the structure maps (Pls. XI, XII) the contour lines are drawn to show every increase of 10 feet in elevation. In the area represented between any two adjacent lines the strata therefore dip 10 feet. The lines are most closely spaced where they represent areas in which the dip is steepest.

In the area under discussion the top of the Whitehorse sandstone was used as a key horizon. But as the top of this sandstone could be identified only where it was capped by the overlying limestone and gypsum beds, and as these beds were widely eroded it was necessary to project the structure contours in places over wide areas. In such areas dips were determined by plotting elevations on a large scale on stratification planes of the Whitehorse sandstone, care being taken to use only planes between beds that were horizontally bedded.

STRUCTURE OF THE CEMENT AREA.

CEMENT ANTICLINE.

The major structural features of the Cement oil field and the area of four townships in which it lies (see Pl. XI) consist of two prominent synclinal folds separated by the Cement anticline, whose axis extends N. 70° W. along the northern part of South Cement Township and the southern parts of North Cement and Tonkawa townships. The arch of the fold parallels the Wichita Mountain folding and conforms closely to the Keeche Hills water divide. (See Pl. XI, in pocket.) The area of closure, which is marked by the 1,460-foot contour line, is about 11 miles long and 2 miles wide, covering approximately 23 square miles. The amount of closure of the anti-

cline, independent of the two domes occurring along its axis, is 60 feet, the highest contour on the anticline being the 1,510-foot contour.

The two domes, representing separate areas of intensive folding along the axis of the anticline, lie about $4\frac{1}{2}$ miles apart. The eastern dome, here called the Cement dome, as it centers 1 mile east of Cement, has a length of 3 miles and a width of $1\frac{1}{2}$ miles. The closure represented by this dome, considered as a separate feature, is 60 feet, and that of this part of the entire fold 120 feet. The dip of the strata in every direction from the crest of the dome is about 100 feet to the mile. The structure of this dome is based on elevations on the Prosperity oil sand and on the top of the Whitehorse sandstone on hills that are capped by gypsum. The interval between those two strata is estimated at 2,460 feet. The structure of the dome as represented may be found to vary slightly from the true structure when more wells are drilled in the area, for erosion has removed the top of the Whitehorse sandstone, leaving only scattered outliers covered by the gypsum, which in places may rest unconformably on the sandstone, and consequently the outcrops and the well logs now available furnish so few points for the determination of elevations that it is impossible to be as certain of the structure in the areas covered by these domes as in adjoining areas. Because of the unconformity previously discussed, some of the dips measured on the contact between gypsum and sandstone may not be structural dips. On Cedar Top, a high butte in the northeastern part of sec. 10, South Cement Township, the base of the gypsum bed outlier, which is 400 feet long and 100 feet wide, has a dip of $3\frac{1}{2}^{\circ}$ S. 20° E. On a second and smaller outlier of the same bed on the water-tank hill, in sec. 2, the dip is even greater than this and in about the same direction. The same bed caps the hill at the eastern edge of Cement, where in 1,200 feet it has a dip to the southeast of only 10 feet.

The center of the western dome, which may be called the Keeche dome, lies just southeast of the center of sec. 36, Tonkawa Township, about $4\frac{1}{2}$ miles west of the Cement dome. The area of uplift of this dome is smaller than that of the Cement dome, being $1\frac{1}{2}$ miles long and three-quarters of a mile wide, but the fold is more intense. The closure of the dome itself is 140 feet, and the total closure of this part of the anticline is 200 feet. The strata dip at the rate of 420 feet to the mile on the northern flank of the dome and about 360 feet to the mile on the southern flank, showing structural dips probably steeper than are found in the surface rocks of any other oil field of Oklahoma. There is some question as to the amount of folding of the center of this dome, for here, as in the Cement dome, the Cyril gypsum is absent except for what appears to be a small remnant up the western slope of the high ridge that lies along the axis of

this dome, and where the gypsum is absent it is impossible to recognize the top of the Whitehorse sandstone. This small gypsum bed, though quite unlike the Cyril gypsum outside of the dome areas, is similar in appearance to the gypsum on the buttes on the Cement dome and may logically be assumed to be the same bed. With the exception of this small outlier, the rest of the ridge is composed of the hard gray calcareous phase of the Whitehorse sandstone, the change in the appearance of the sandstone and the Cyril gypsum being due chiefly to the action of ground water, as explained on page 54. The position of the center of the fold and the highest contour are based on the elevation of the highest part of this high ridge, the surface rocks here being considered the top of the Whitehorse sandstone. If this correlation is erroneous the folding is even more pronounced than has been represented. The structure of the rest of the dome has been determined from the available well logs.

The axis of the Cement anticline extends about 4 miles northwest of the Keeche dome and about 3 miles east of the crest of the Cement dome. At each end the anticline is terminated by a syncline. On the flanks of the Cement anticline the rocks dip to synclinal basins at a rate that averages 60 feet to the mile, but decreases toward the synclinal areas. The axis of the syncline on the northern flank, here called the Cobb syncline, lies 2 miles from the center of the Cement dome and 3 miles from the Keeche dome; the difference in the elevation of the top of the Whitehorse sandstone on the crests of the domes and in the bottom of the syncline is 140 and 250 feet, respectively. The axis of the Cyril syncline, on the southern flank, lies $4\frac{1}{2}$ miles down the dip from both the Cement and Keeche domes, and the differences in elevation of the top of the Whitehorse sandstone are 250 and 340 feet, respectively. The strata thus dip 100 feet lower on the southern flank than on the northern, and the Keeche dome is structurally 80 feet higher than the Cement dome.

CYRIL SYNCLINE.

The Cyril syncline, so named by F. G. Clapp, consists of a broad central basin, the center of which lies about 2 miles west of Cyril. Across this area the axis of the syncline curves to the east and northwest. (See fig. 8.) On the northwest the syncline terminates where it cuts off the Cement anticline. On the east the synclinal basin probably extends for several miles beyond the area mapped. Northward from the center of the syncline the strata rise just enough to expose the gypsum-capped top of the Whitehorse sandstone along the sides of the streams to their heads in the Keeche Hills. To the south and west, in Doyle Township, up the flanks of the syncline, the Cyril gypsum rises at the rate of 40 feet to the mile and is exposed

along the sides of the streams that flow into the Little Washita, in some places only a few feet above the stream beds for long distances. About 2 miles south of the Little Washita the lower gypsum bed crops out continuously along the western and southwestern parts of Doyle Township. This outcrop forms a ridge which some geologists have believed to indicate the presence of an anticlinal fold. However, elevations on the base of the gypsum bed on the west side of the divide and across the divide where it has been dissected by stream channels, which expose the contact between the Whitehorse sandstone and the gypsum bed, prove that the dips are all to the northeast and hence that no anticline is present. In the township south of Doyle the gypsum bed rises toward the south and forms a continuous outcrop at the base of a prominent high ridge just east of Fletcher. Thus this ridge is not due to an anticlinal uplift but is an escarpment of the gypsum bed. It is very probable that the rocks south and southwest of the Cyril syncline rise continuously out of this basin to the Wichita Mountain uplift. Across the township lying between Doyle and the northeastward-dipping Cambrian and Ordovician limestone along the northeast side of the Wichita Mountains the outcropping strata probably belong principally to the Woodward formation, being mostly shales which have weathered into a low-lying plain. These shales include no beds from which the structure of the area can be definitely determined. A sandstone that crops out in the village of Apache was traced for 3 or 4 miles to the southeast. This sandstone dips to the northeast, and it is very probable that there is a continuous dip of the Permian rocks away from the mountains to the Cyril and Cobb synclines.

COBB SYNCLINE.

From 2 to 3 miles north of the Cement anticline lies a synclinal basin whose axis, beginning near the southeast corner of North Cement Township, extends northwestward to the northwest corner of Tonkawa Township and thence northwestward diagonally across the whole of the Kiowa area, forming one continuous synclinal fold. In the Cement area this synclinal fold is to be considered as a shallow basin ending near the southeast corner of North Cement Township and deepening toward the northwest. The strata rise rather steeply up the southern flank, but on the northern flank the dip is only 20 to 30 feet to the mile. The outcrops of the Whitehorse sandstone capped by gypsum are few in Tonkawa and North Cement townships, and hence the exact form of the Cobb syncline in these townships can not be determined with as much certainty as that of its central portion in West McKinley Township. There is, however, an almost continuous outcrop of the key rock along ridges running northward along

the east and west sides of Tonkawa Township, which gives a line of elevations across the syncline at about right angles to the strike. The last outcrop of the top of the Whitehorse sandstone up the northern flank of the syncline is on the top of a hill 1,800 feet west of the northeast corner of Tonkawa Township. The elevation of the key rock here shows a rise of the strata to the northeast. The continuation of this northeastward rise is shown by the southwesterly dips of a 25-foot massive layer of the Whitehorse sandstone and a 2-foot gypsum bed, occurring respectively at the top and base of the bluffs along the river valley southeast of Anadarko. The gypsum bed lies 230 feet below the top of the Whitehorse sandstone and can be traced along the ridge extending out in the valley of the Washita on the east side of the series of lakes through which Tonkawa Creek flows. The dip of the gypsum bed here makes it possible to determine the position and direction of the contour lines, and as the region as a whole is characterized by straight contours, it is permissible to project the structure across broad areas in which there are no outcrops. It is therefore considered that the structure as mapped for the northern part of Tonkawa Township and the most of the township north of it is correctly indicated on the map, in spite of the absence of many points of control. These conditions exist in North Cement Township, though in that area there are fewer outcrops than in Tonkawa. The axis of the syncline shown on the structure map was located by projecting an even curve through three points where its position was definitely determined. These points are in secs 6 and 14, Tonkawa Township, and sec. 27, North Cement Township. The determinations in secs. 6 and 14 were made by running a line of levels along the base of the Cyril gypsum, which occurs in a continuous outcrop across the bottom of the syncline. In sec. 27, North Cement Township, the axis cuts across the northernmost two outliers of the Cyril gypsum northeast of the Keeche Hills. The dip on the northeast flank of the syncline can not be accurately determined here, but the fact that the strata rise toward the northeast at this point is shown by a slight but definite dip to the south in the gypsum that caps the outlier in sec. 27 and by the fact that no gypsum appears on the hills to the north, which are high enough to be capped with this bed if it did not rise toward the north.

Some of the geologists who have examined this area believe that the gypsum is present under the sand hills to the north, concealed by the sand, instead of having been stripped off as postulated by the writer. The work done in other parts of the area refutes this belief, for throughout the eight townships mapped not a hill or a ridge underlain by the gypsum fails to show some outcrop of this characteristic bed, particularly on southwesterly exposures. The existence of a large area of drifted sand is itself evidence that the surface is under-

lain by the Whitehorse sandstone and not by the gypsum, for where the gypsum is present the soil is less sandy and the surface does not become sand covered.

Additional evidence of the southwesterly dip of the rocks is found in the dip of the stratification planes of the Whitehorse sandstone in sec. 11, North Cement Township, and also by the outcrops of the gypsum bed that underlies the Whitehorse sandstone a few miles north and east of Cement. That the axis of the syncline swings to the southwest and cuts off the Cement anticline is indicated by the dip of hard ledges in the Whitehorse sandstone in sec. 1, South Cement Township, and sec. 7 of the township to the east. The data that permitted the determination of the position of this syncline are set forth above in some detail, because the statement has been made by several observers that the dips on the flank of the Cement anticline continue several miles to the northeast. The erroneous impression on which this statement is based seems to be due to confusion of the Cyril gypsum with a bed of gypsum that crops out between Chickasha and Ninnekah and that actually lies about 230 feet below the Cyril gypsum.

STRUCTURE OF THE KIOWA AREA.

The chief feature of the structure of the Kiowa area (see Pl. XII, in pocket) is the Cobb syncline, whose axis extends diagonally across the whole area. The lowest point of the syncline lies in the southern part of West McKinley Township. Away from this low point the rocks rise in every direction—gently along the synclinal axis and more steeply up the flanks of the syncline. To the northeast the rise is at first only about 20 feet to the mile, but farther north, in Grand View Township, the dip increases to almost 40 feet to the mile. In the northwestern part of this township there is a slight buckling or arching of the strata, which may represent the nose of an anticline lying to the north. However, the outcrops of the key rocks are so few that the character of this possibly anticlinal fold can not be determined with absolute certainty. A minor synclinal fold, which runs northward across the center of the township, appears to be the only definite fold in the whole area mapped that does not parallel the structural trend of the region. The Cobb syncline apparently continues through North and South Cobb townships. Over much of this area there are no outcrops of the gypsum bed, but as the structure of the region as a whole is marked by uniformity of strike, it is thought that the structure as shown by broken lines on the map is very close to the true structure. Fortunately there are some points of control that justify drawing the contour lines northwest of the main areas of outcrops in Grand View Township and in the eastern part of South Cobb Township.

In sec. 34, North Cobb Township, there is a small outlier of gypsum. This, taken together with the outcrop in the northern and western parts of the township, supported by a few dips determined on stratigraphic planes of the Whitehorse sandstone in the western part of South Cobb Township, makes it possible to determine with a considerable degree of certainty the structure of an area which is almost entirely covered with wind-blown sand. If this area were studied alone, its structure could not be determined at all. The northwestward extension of the synclinal axis is suggested by the fact that its projected axis conforms in position and direction with Cobb Creek, which, from a consideration of its character and similarity to other synclinal creeks of the region, is apparently a synclinal stream. West of North Cobb Township there is a broad belt covered by the Cyril gypsum, which dips to the northeast across the first township, beyond which no observations were made. The 1,560-foot contour is a projection of the strike of the Cyril gypsum from a point where its base has this elevation, 6 miles west and 1 mile south from the northwest corner of North Cobb Township.

The Cyril gypsum can be traced southward from the center of the Cobb syncline up the dip to the top of the ridge that forms a continuation of the Keeche Hills water divide. To the southwest of this ridge the country is a low-lying plain in which all the surface strata are red and green shales, and in this area the dips of the rocks can not be determined. The ridge, being a continuation of the Keeche Hills water divide, is regarded by some oil men as a continuation of the Cement anticline. This belief is in error, for the Cyril syncline cuts off the fold in the western part of Tonkawa Township. That another fold is not developed farther west at the position of this ridge is proved by the fact that to the southwest the surface formations are the shales that form the base of the Whitehorse sandstone. If the ridge were an anticline, then the strata would dip to the southwest and the surface would be underlain by the upper part of the Whitehorse sandstone and the overlying Cyril gypsum. Again, this area is obviously a part of the structural belt which, to the southeast and northwest, is known to dip northeast. Hence the ridge is to be interpreted as an escarpment produced by the outcropping gypsum beds.

RELATION OF STRUCTURE TO TOPOGRAPHY.

As the "plain" surface forming the flat-lying upland of this region owes its presence to the underlying gypsum bed (see p. 42), the folding of this gypsum bed is reflected in the general slope of the country which it underlies, although the minor topographic features of course have no relation to structure, being determined by

streams or wind erosion. Thus, in the Cement area the position of the Cement anticline is marked by a high divide and that of the synclinal basin to the south by relatively low country, because the Cyril gypsum is the surface formation in both localities. In the Kiowa area the general slope of the country underlain by the Cyril gypsum or the Day Creek dolomite conforms to the dip of the strata.

However, this does not mean that all ridges and all slopes in this region are due to the structure, as many oil men have come to

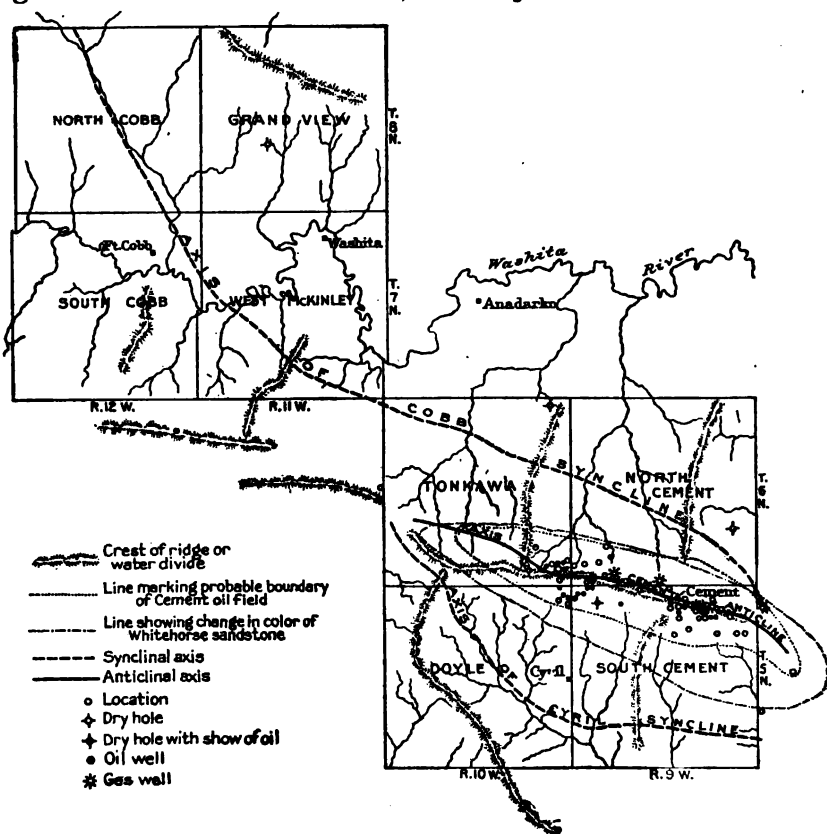


FIGURE 8.—Map showing absence of relation of ridges to structure and other features in the Cement oil field, Caddo County, Okla.

think. In fact, the relation between the Keeche Hills and the Cement anticline is to be regarded as unusual and due to the fortuitous combination of a number of circumstances. In the country outside of the Keeche Hills the only topographic features related to the structure are the regional slopes of the upland areas underlain by the gypsum. These slopes are so mild and irregular that they are scarcely determinable except when the landscape as a whole is considered. All the ridges and valleys on such slopes are due to the erosive action of the wind and streams and have no rela-

tion to structure. Such topographic features include many of the prominent ridges that lie between streams flowing in the same direction. The land slopes that are not underlain by the Cyril gypsum do not owe their direction of slope to the dip of the underlying rocks. These include the broad valley slopes of the rivers and the steeper slopes of the prominent escarpment ridges produced by the outcrops of the Cyril gypsum, as, for example, the ridges in the western part of Grand View Township and the eastern part of South Cobb Township, the water divide 1 mile south of West McKinley Township, and the ridge in the western part of Doyle Township, which extends southeastward into the township south of Doyle. Such a ridge can be readily distinguished from an anticlinal ridge, like the Keeche Hills, by the presence of the gypsum on one slope and its absence on the other. The lack of relation between these ridges and the structure of the region is shown in figure 8.

DEVELOPMENT OF CEMENT OIL FIELD.

HISTORY OF DEVELOPMENT.

Operations for the development of oil and gas in this region began in 1916, near the present Cement field, with the drilling of a shallow well on the Funk farm, 3 miles east of Cement (No. 72, Pl. XI), in which, at a depth of 1,415 feet, half a million cubic feet of gas was encountered. Active drilling in the area was started by the completion in 1917 of the Kunsemuller well, in sec. 32, North Cement Township, by the Oklahoma Star Oil Co. This well encountered sufficient oil at a depth of about 1,700 feet to encourage further drilling, and as a result the Fortuna Oil Co., during the same year, drilled a well in sec. 31, North Cement Township (No. 20, Pl. XI). This well found gas and gave an initial production of 35,000,000 cubic feet from a sand 2,340 feet deep. In 1918 wells yielding oil from depths of about 2,300 feet in sufficient quantities to prove that a commercial oil field had been found were completed in both the eastern and western parts of the field. Since then development work has continued, and at the time of writing (Mar. 1, 1920) there are 26 completed wells in the field and 36 wells being drilled. Of the completed wells, 20 are oil wells, 4 are gas wells, and 2 are abandoned holes. Of the wells now being drilled, three have gone through the present producing sands without finding oil. These wells will be drilled deeper.

OIL SANDS.

The oil produced so far in this field has come from a series of shales and sandstones (the oil-sand group in the table on p. 57), which underlies the surface at depths of 1,500 to 2,400 feet. Good showings of oil are encountered in many of the sandstones of this group, but at present the production is confined chiefly to three sands.

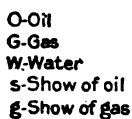
Caddo oil sand.—The highest producing sand, known as the Caddo or 1,800-foot sand, yielded oil in paying quantities for the first time in the Roe well No. 2 of the Caddo Petroleum Co., in the west end of the field (No. 12, Pl. XI). Although this well is the best producer in the field, offsetting wells have obtained but little more than a show from this sand, and so far this well and the Foster Oil Co.'s Gingrich well No. 2 (No. 39, Pl. XI) are the only wells producing from it. The logs of most wells in the west end of the field, however, record a sand that gives a show of oil at this horizon, so it may prove to be a more persistent producing sand than past development would indicate. This would not be surprising, as many wells were drilled through it with a rotary drill. The Caddo sand is from 20 to 40 feet thick. It is a quartz sand in which the grains are of various shapes and sizes, but in general partly rounded and from 0.1 to 0.3 millimeter in diameter. Above the sand are a series of soft brown shales and water-bearing sandstones. The Caddo sand is about 1,890 feet below the top of the Whitehorse sandstone.

Fortuna oil sand.—At about 500 feet below the Caddo sand occurs the Fortuna or 2,300-foot sand, which is the chief oil producer in the west end of the field. This sand was tested for the first time by the Fortuna Oil Co.'s well in the southwest corner of sec. 31, North Cement Township (No. 20, Pl. XI). In thickness it ranges from a few feet to 50 feet. It becomes shaly toward the east and is not a producer in the east end of the field, unless the gas sand there, 60 feet above the oil sand, is to be considered the Fortuna sand. The interval between the top of the Whitehorse sandstone and the Fortuna sand is about 2,385 feet, though owing to the inclination of the strata the logs of wells drilled in the Keeche dome record about 2,400 feet of intervening strata.

Prosperity oil sand.—About 80 feet below the horizon of the Fortuna sand and 2,465 feet below the top of the Whitehorse sandstone is a third oil sand, here called the Prosperity sand, because oil was first obtained from it in the Prosperity Oil Co.'s well on the Cutshall farm, in sec. 5, South Cement Township (No. 43, Pl. XI). In this well the producing sand is about 100 feet below what is apparently the Fortuna sand, which is here but 2,335 feet below the top of the Whitehorse sandstone, showing a slight decrease in the thickness of the rocks to the southeast. This sand is the chief producing bed in the east end of the field and probably is the deepest sand from which oil is obtained in the Fortuna Oil Co.'s Gregory well, in the west end of the field (No. 20, Pl. XI). The Prosperity sand is a brownish fine-grained quartz sand, in which the grains are rounded, of uniform size, and about 0.1 millimeter in diameter.

Discovery of new sands.—It is quite probable that some of the other sandstones of this group may prove productive if they are

WELL WELL WELL WELL WELL WELL
No.5 No.11 No.12 No.20 No.38 No.42



Sand Shale, blue Shale, red brown

PLOTTED LOGS OF 11 WELLS IN

properly tested. There has been considerable conjecture as to the possibility of finding oil at greater depths in the Cement field. Apparently this is a possibility, for the oil now obtained probably comes from the top of the Pennsylvanian, and there are prolific oil-bearing sands in the middle and lower part of the Pennsylvanian in Oklahoma and northern Texas. At just what depth deeper oil sands may be encountered it is impossible to determine, but probably they lie at least 800 feet beneath the Prosperity sand, for the deep test in the area and the wells drilled in adjoining counties show several hundred feet of blue and red calcareous shale beneath the oil-sand group. Below these shales sandstones were encountered in the Cothlin and Kunsemuller wells (Nos. 5 and 23, Pl. XI) at depths of 3,520 and 3,440 feet, respectively. In the Cothlin well the sandstone is water bearing. In the Kunsemuller well only the top was penetrated, so what it will yield is not yet known. Below these depths sandstones will probably be encountered every hundred feet or so, and in some of them oil may be found, but the chances for finding it are best in the dome areas, for the sandstones showed large amounts of salt water in all wells that penetrated them in adjacent counties, indicating the necessity of drilling as far as possible up the slopes of the anticline.

PRODUCTION OF WELLS.

The present production of the 20 oil wells of this field is approximately 1,200 barrels a day. About 300 barrels of this is taken by the Cyril Refining Co., and the remainder is either stored in the field or piped to the Cement loading station.

The oil wells show an average initial daily production of about 100 barrels. The largest well brought in so far is a 300-barrel well. The low initial production is offset by the slow decline of the wells, as noted on the well table on page 77. The rate of decrease from the initial production averages about 2 per cent a month, which indicates that the wells will have a life of six or eight years at least. The gas wells, however, show a rapid decrease, their initial production of several million cubic feet a day being reduced to less than half a million feet in a few months, and in the Calla Belle No. 2, east of Cement (No. 55, Pl. XI), the production decreased to this amount in a few days.

EXTENT OF THE FIELD.

It is difficult, considering the present progress of the development of the field and the apparent lenticularity of the oil sands, to make any definite estimate as to the probable extent of the Cement field. However, it appears very likely that the area of production will be limited to the area of closure, or the territory lying within the 1,460-foot contour line, and it is obvious that all of this area will not produce oil, for of the 29 wells drilled inside this area through

the oil-sand group only 20 are producing oil, 4 are producing gas, and the remainder are nonproductive. Even if 3 of the gas wells are considered potential oil wells, only about 75 per cent of the wells drilled through the horizon of the producing sands yield oil, and if it is granted that this percentage will not decrease, which is doubtful, considering the fact that drilling has progressed around producing wells rather than around dry holes, it is possible that of the 22 square miles lying within the area of closure 16 square miles, or, say, 10,000 acres, will prove productive of oil. But the probabilities are that not half of this area will be productive.

GRADE OF OIL.

The oil from the different wells is very similar in appearance, and apparently its quality is comparatively uniform. The color by reflected light is black. The gravity of three samples, two of which were analyzed by George Steiger in the laboratory of the United States Geological Survey and the third by E. W. Dean, of the Bureau of Mines, ranged between 0.84 and 0.85 (37° and 34.7° Baumé). The analyses are given below:

Analyses of oil samples from Cement field, Caddo County, Okla.

[Results of open-column distillation at atmospheric pressure.]

Niles well No. 1, Fortune Oil Co.

[Specific gravity of crude oil, 0.840.]

Temperature (°C.).	Percentage by weight.		Specific gravity at 25° C. 25° C.
	Fraction.	Total.	
43 to 100.....	2.8	2.8	0.704
100 to 125.....	2.5	5.3	.730
125 to 150.....	3.5	8.8	.746
150 to 175.....	4.4	13.2	.763
175 to 200.....	4.2	17.4	.775
200 to 225.....	5.2	22.6	.778
225 to 250.....	12.5	35.1	.805
250 to 275.....	17.8	52.9	.828
Above 275.....	36.8	89.7	.829
Residue.....	7.5	97.2	.....
Loss.....	2.8	100.0	.....
	100.0	.....	.....

Roe well No. 2, Caddo Petroleum Co.

[Specific gravity of crude oil, 0.849.]

68 to 100.....	3.7	3.7	0.718
100 to 125.....	1.3	5.0	.745
125 to 150.....	2.7	7.7	.751
150 to 180.....	6.5	14.2	.764
180 to 200.....	5.9	20.1	.778
200 to 225.....	9.5	29.6	.793
225 to 250.....	7.3	36.9	.810
250 to 275.....	6.8	43.7	.824
Above 275.....	44.8	88.5	.833
Residue.....	6.3	94.8	.....
Loss.....	5.2	100.0	.....
	100.0	.....	.....

Analyses of oil samples from Cement field, Caddo County, Okla.—Continued.

Paakune well No. 1.

[Specific gravity at 15° C., 0.850 (34.7° Baumé).]

Temperature (°C.).	Air distillation, with fractionating column. (Barometer 736 mm.)		Vacuum distillation, without column. (Pressure 40 mm.)			
	Percentage by volume.		Specific gravity.	Percentage by volume.		Specific gravity.
	Fraction.	Total.		Fraction.	Total.	
Up to 50.....	0.5	0.5				
50 to 75.....	1.0	1.5	0.715			
75 to 100.....	2.6	4.1				
100 to 125.....	4.6	8.7	.750			
125 to 150.....	5.0	13.7	.765			
150 to 175.....	6.1	19.8	.775	0.4	55.6	
175 to 200.....	5.8	25.6	.785	1.0	56.6	0.855
200 to 225.....	6.8	32.2	.800	3.6	60.2	
225 to 250.....	7.7	39.9	.815	5.9	66.1	.860
250 to 275.....	7.0	46.9	.827	5.6	71.7	.871
275 to 300.....	8.3	55.2	.840	4.2	75.9	.879
Residue.....						

RECOMMENDATIONS AS TO FUTURE DEVELOPMENT.

It is obvious that in the further development of the Cement field the best policy is to drill outward from the producing wells in locations at least 600 feet apart or at least to confine new developments to the two domes—that is, to areas within the 1,520-foot contour line or in the structural belt lying between the 1,520 and 1,460 foot contours. The area outside of this belt is likely to be nonproductive territory and should be drilled only after development has proved the existence of oil inside the belt. If the producing area is extended by drilling adjacent to the wells that now yield oil or gas, a dry hole or a small producing well may define the edge of the field, especially if open-textured sands or large volumes of salt water are encountered. On the other hand, dry holes, drilled at random along the flanks of the anticlines in the earlier development of the field, will be much less indicative of the limits of the field. The tendency will be to consider the territory for some distance around such holes of small value, whereas it is entirely possible that an isolated hole thus drilled at random is in reality on the very edge of a producing area. In many of the oil fields of the country this possibility is illustrated. For example, one of the offsets to the discovery well in the Healdton field was dry, and an offset to the discovery well in the Ranger field produced only relatively small quantities of petroleum. Almost every oil field of importance has within its limits some dry holes, and along some parts of its margins the line of demarcation between productive and barren area is very sharply drawn.

It is also a questionable policy to drill wells to the producing sands in the areas at the centers of the domes, for the oil sands in those

areas probably contain gas, the expansive force of which, if it were left in the sand, would tend to force the oil out of the sand into the oil wells and thereby make it possible to recover a greater proportion of the oil. Unfortunately, however, under the present competitive system of developing oil fields, the laws governing development are based on a consideration of property rights rather than of natural laws, and consequently there is not only a waste of capital and materials but a waste of the oil itself.

POSSIBILITY OF FINDING OIL OUTSIDE OF THE CEMENT FIELD.

The observed relations of structure and oil accumulations in the Cement field indicate that there is slight possibility of oil being found anywhere in the area mapped outside of this field, which will probably not extend beyond the area included within the 1,460-foot contour line and hence will be confined to a narrow strip not more than 2 miles wide in its broadest part and extending 7 miles northwest and 5 miles southeast of Cement. Small showings may be encountered in wells drilled outside of this area, but it is doubtful if such showings will indicate the presence of a commercial pool near by. Pockets of oil and gas may be discovered where small amounts of these materials have been trapped in porous lenses of sandstone by circulating ground waters, but the chances of finding such lenses are small, and their commercial value is not, as a rule, equivalent to the cost of drilling more than a very small number of wells. The slight buckling of the strata in the northwest corner of Grand View Township probably does not represent sufficient folding to effect the segregation of a pool, but there is a bare possibility that it marks the south end of an anticline lying to the north. As discussed on page 69, it appears very unlikely that the ridge south of West McKinley and South Cobb townships is underlain by an anticline, and hence oil may not be expected to be found in either the Humble well or the Simons well (Nos. 3 and 1 in the following table).

WELL TABLES.

Wells in Cement oil field, Caddo County, Okla.

[Prepared in March, 1920.]

No. on map.	Township and farm.	Company.	Date completed.	Total depth (feet).	Product.	Sand.	Daily production (barrels).		Elevation (feet).		Depth to For- tuna sand (feet).	Depth to Pro- perly sand (feet).
							Initial.	Present.	Well mouth. stone at well.	White- horse sand- stone		
1	T. 6 N., R. 12 W. Dorley No. 1.....	Simons et al.....	Rig.....						1,408			
2	T. 8 N., R. 11 W. (?).....	Daw-Bell Development.....	(?).....	2,505	Dry.....				1,439	1,428		
3	T. 6 N., R. 11 W. Fiers No. 1.....	Humble.....	Drilling.....	1,216					1,427	1,426		
-	T. 6 N., R. 10 W. (Tonkawa).											
4	W. Melton No. 1.....	Anadarko Producers.....	Drilling.....	3,640	Dry.....				1,434	1,485	2,340	
5	Cochin No. 1.....	Fortuna.....	Drilling.....						1,476	1,490	2,275	
6	Mcrauo No. 1.....	do.....	Drilling.....						1,499	1,610		
7	Lindsay No. 1.....	McKinney.....	Drilling.....	600	Dry.....				1,565			
8	Mrs. Ritter No. 1.....	J. S. Henry.....	June 30, 1919.....	2,362	Oil.....	Fortuna.....	150	100	1,439	1,550	1,813	2,322
9	Niles No. 1.....	do.....	Feb. 19, 1919.....						1,515			
10	Lindsay No. 1.....	do.....	Feb. 21, 1919.....	2,350	Oil.....	Fortuna.....	60	45	1,427	1,530	1,800	2,304
11	Roe No. 1.....	Caddo.....	Aug. 13, 1919.....	1,821	Oil.....	Caddo.....	315	255	1,445	1,525	1,807	
12	Roe No. 2.....	do.....	Drilling.....						1,447	1,550	2,330	
13	Roe No. 3.....	do.....	Drilling.....						1,446			
14	Roe No. 1.....	Seaman Depositors.....	Drilling.....			Caddo.....			1,446	1,520	1,760	
15	Roe No. 1.....	Gladstone.....	Drilling.....						1,417			

e Log shows no sand at this depth, but the beds are about at the depth indicated.

Wells in Cement oil field, Caddo County, Okla.—Continued.

No. on map.	Township and farm.	Company.	Date completed.	Total depth (feet).	Product.	Sand.	Daily production (barrels).		Elevation (feet).		Depth to Caddo sand (feet).	Depth to Fortuna sand (feet).	Depth to Prosperity sand (feet).
							Initial.	Present.	Well mouth.	White-horse sandstone at well.			
T. 6 N., R. 9 W. (North Cement).													
16	Westervelt No. 1.	(?)	Drilling	2,340		Caddo			1,469	1,525	1,785		
17	Westervelt No. 1.	American	Drilling						1,424				
18	(?)	Ohio Fuel.	Drilling						1,395				
19	Barry No. 1.	Lemasters	Drilling										
20	Gregory No. 1.	Fortuna	(?)		Gas (Oil)	Fortuna	(?)	200	1,529	1,570		2,340	
21	Stark & Gregory No. 1.	Lone Star	Drilling						1,454				
22	Lucy Jones No. 1.	Gladstone		2,300	Oil	2,240	25	40	1,430	1,505		2,290	
23	Kunsenmiller No. 2.	Cement Field		3,441	Dry				1,467	1,500		2,325	
24	Baldwin No. 1.	Expansion.	Drilling						1,382	1,470		1,806	
25	Mrs. Henry No. 1.	Betty O.	Nov., 1918	2,318	Oil	2,258	75	10	1,380	1,480		2,350	
26	Kunsenmiller No. 2.	Cement Field.	May, 1919	2,325	Gas	Fortuna	5,000,000	0	1,433	1,500		2,300	
27	Day No. 1.	Trigo	Aug.						1,457				
28	Wooten No. 1.	Hill.	July, 1919	2,434	Gas oil.		5,800,000	5,500,000	1,309	1,500		2,280	
29	(?)	(?)		1,200	Dry								2,280
T. 5 N., R. 10 W. (Doyle).													
30	Davis No. 1.	Keeche	May 14, 1919.	2,354	Oil	Fortuna	175	100	1,498	1,522		2,324	
31	Davis No. 1.	Columbia	Dec. 1919	2,368	Oil	Fortuna	(?)	50	1,475	1,505		2,332	
32	Davis No. 2.	do	Drilling						1,486				
33	Walker No. 1.	Central Producers.	Oct. 1919	2,394	Oil	Fortuna	150	75	1,492	1,490		2,362	
34	Davis No. 2.	do	Drilling						1,483				
35	Walker No. 3.	do.	Drilling						1,456				
T. 5 N., R. 9 W. (South Cement).													
36	Gingrich No. 1.	Lone Star	Drilling	2,285	Oil	Fortuna			1,500			2,367	
37	Gingrich No. 1.	Fortuna.	Feb., 1919.				100	80	1,522	1,500		2,309	
38	Gingrich No. 1.	Foster	Oct., 1919	2,330	Oil	Fortuna.	80	35	1,463	1,513		2,367	
39	Gingrich No. 2.	do.	Feb., 1920.	1,939	Oil	Caddo.	100	100	1,518	1,500	1,918	2,367	
40	Culp No. 1.	Hawkeye.	July, 1919.	2,319	Oil	Fortuna.	60	20	1,439	1,505		2,296	

43	McKinney No. 1	Fortuna	May, 1918	Oil	Prosperity	85	10	1,431	1,485	2,385
44	Cutshall No. 1	Lone Star	Drilling					1,420	1,500	2,267
45	Lemp No. 1	Cunningham et al.	Drilling					1,465		
46	J. Marshall No. 1	Cement Drilling	Drilling							
47	Holding No. 1	Hemlock	Drilling					1,448	1,542	2,387
48	Parkme No. 1	Gladstone	Aug., 1919	Oil	Prosperity	180		1,452	1,545	2,375
49	Parkme No. 2	do	do	Oil	Prosperity			1,459	1,545	2,384
50	Parkme No. 3	do	Mar. 10, 1920	Oil	Prosperity			1,515		
51	City Park No. 1	Yukon Cement	Rig					1,458	1,555	2,375
52	Surbeck No. 1	do	Drilling					1,451	1,595	2,375
53	Surbeck No. 2	do	Aug. 4, 1919	Gas	Prosperity	2,000,000		1,431	1,555	2,330
54	Surbeck No. 1	Calla Belle	Feb., 1919	Oil	Prosperity	50	40	1,420	1,555	2,335
55	Surbeck No. 2	do	Feb., 1920	Gas	Prosperity	17,000,000	200,000	1,448	1,568	2,330
56	Wade No. 1	Gorton	do	Gas	Prosperity	2,270		1,413	1,560	2,330
57	Wade No. 2	do	Oct., 1919	Oil	Prosperity	100	85	1,411	1,545	2,313
58	Wade No. 3	do	do					1,472		
59	Lemon No. 1	Concrete	Drilling					1,453	1,563	2,330
60	Mrs. Yeul No. 1	McKinney	Rig					1,489		
61	Klading No. 1	Gladstone	Drilling					1,420	1,540	2,380
62	(?)	Ross	Rig							
63	Estes No. 1	United Cement	Drilling					1,495	1,485	2,470
64	Rigley No. 1	Livermore-Rimmel	Drilling					1,444		
65	Lacey No. 1	National Producers	Drilling					1,419		
66	Lacey No. 1	Mid-Southwestern	Drilling					1,402		
67	Lacey No. 1	Betty G.	Dec. 1919	Oil	Prosperity	75	50	1,426	1,540	2,334
68	Mrs. Headland No. 1	McKinney Oil & Drilling Co.	Drilling					1,417	1,440	2,321
69	McKenna No. 1	Nix et al.	Drilling					1,348	1,480	2,315
70	Rigney No. 1	Gorton	Drilling					1,870	1,475	2,340
71	Wagner No. 1	do	Drilling					1,371	1,475	
<i>T. S. N., R. & W.</i>										
72	Funk No. 1	Star	Drilling	Gas	7,415	500,000		1,283		
73	Shook No. 1	Knox	Drilling					1,300		
74	(?)	Hayley	Rig					1,207		

a Log shows no sand at this depth, but the beds are about at the depth indicated.

b Cubic feet.

c Well not drilled to this depth, but this is approximately the depth at which the sand should be reached.

Driller's logs of wells in Cement oil field, Caddo County, Okla.

Daw-Bell Development Co., sec. 21, Grand View Township.

[No. 2, Pl. XII. Nonproducer.]

	Feet.		Feet.
Surface clay	0- 12	Red bed	1, 254-1, 290
Rock sand	12- 365	Limerock	1, 290-1, 298
Soft water sand	365- 375	Brown shale	1, 298-1, 350
Red gumbo	375- 380	Red clay	1, 350-1, 380
Sandrock	380- 396	Red sandy shale	1, 380-1, 470
Red bed	396- 428	Red bed and gip	1, 470-1, 500
Brown shale	428- 456	Red sandy shale	1, 500-1, 570
Gip	456- 461	Red bed and shale	1, 570-1, 620
Red joint clay	461- 476	Hard limerock	1, 620-1, 634
Red gumbo	476- 482	Red bed and shale	1, 634-1, 646
Brown shale	482- 510	Brown shale; showing of	
Gumbo and gip	510- 520	oil	1, 646-1, 650
Brown shale	520- 565	Red clay	1, 650-1, 670
Gumbo and gip	565- 578	Brown shale	1, 670-1, 695
Hard brown shale	578- 610	Red bed or clay	1, 695-1, 750
Red bed	610- 620	Shale and gip	1, 750-1, 810
Gray lime	620- 628	Red clay	1, 810-1, 872
Brown shale	628- 678	Shale and boulders	1, 872-1, 896
Gip	678- 682	Red clay	1, 896-1, 960
Broken lime	682- 694	Shale and gip	1, 960-2, 010
Hard lime	694- 702	Red clay	2, 010-2, 025
Brown shale and gip	702- 722	Hard lime shell	2, 025-2, 030
Joint clay	722- 804	Red bed or clay	2, 030-2, 090
Hard lime shell	804- 806	Shale and gip	2, 090-2, 124
Hard brown shale	806- 810	Red bed and clay	2, 124-2, 160
Joint clay, red	810- 840	Broken lime	2, 160-2, 170
Sandy shale	840- 930	Brown shale; showing of	
Joint clay	930- 990	oil (best show)	2, 170-2, 195
Sandy shale	990-1, 105	Red bed or clay	2, 195-2, 230
Limerock	1, 105-1, 113	Brown shale	2, 230-2, 270
Red gumbo	1, 113-1, 140	Red bed or clay	2, 270-2, 310
Sandy shale	1, 140-1, 170	Hard shale	2, 310-2, 320
Red bed	1, 170-1, 194	Red clay	2, 320-2, 376
Hard lime shell	1, 194-1, 196	Red clay; showing of gip	2, 376-2, 430
Red bed	1, 196-1, 236	Red gumbo	2, 430-2, 505
Gumbo and gip	1, 236-1, 254		

Cothlin well No. 19, Fortuna Oil Co., northwest corner SE. $\frac{1}{4}$ sec. 35, Tonkawa Township

[No. 5, Pl. XI. Commenced June 15, 1918. Nonproducer.]

	Feet.		Feet.
Red sand	25- 75	Hard lime	305- 307
Sand; water	75- 95	Lime	307- 335
Sand	95- 150	Red shale	335- 343
Lime	150- 190	Lime	343- 377
Sand	190- 215	Blue shale	377- 440
Red shale	215- 225	Lime	440- 445
Shale	225- 235	Blue shale	445- 508
Lime	235- 305	Sand	508- 525

*Driller's logs of wells in Cement oil field, Caddo County, Okla.—Continued.*Cethlin well No. 19, Fortuna Oil Co., northwest corner SE. $\frac{1}{4}$ sec. 35, Tonkawa Township—Con.

	Feet.		Feet.
Blue shale	525- 570	Blue slate and oil	2, 011-2, 025
Sand	570- 616	Red beds	2, 025-2, 040
Lime	616- 620	Blue slate	2, 040-2, 050
Sand and iron; water	620- 660	Lime shell	2, 050-2, 053
Blue shale	660- 695	Blue slate	2, 053-2, 063
Lime	695- 720	Lime shell	2, 063-2, 065
Hard lime	720- 725	Red beds	2, 065-2, 100
Blue slate	725- 735	Black shale	2, 100-2, 110
Hard lime	735- 745	Red beds	2, 110-2, 120
Blue slate	745- 750	Blue shale	2, 120-2, 133
Sand; water	750- 760	Sand; oil and gas	2, 133-2, 137
Lime	760- 765	Red rock	2, 137-2, 140
Blue shale	765- 770	Sand	2, 140-2, 145
Lime	770- 780	Blue shale	2, 145-2, 174
Sand; water	780- 800	Sand; gas	2, 174-2, 180
Blue slate	800- 810	Red beds	2, 180-2, 210
Sandy lime	810- 820	Blue shale	2, 210-2, 230
Blue slate	820- 850	Red beds	2, 230-2, 234
Sandy lime	850- 870	Blue shale	2, 234-2, 245
Blue slate	870- 967	Red beds	2, 245-2, 260
Brown shale	967-1, 010	Brown shale	2, 260-2, 290
Blue slate	1, 010-1, 025	Lime	2, 290-2, 293
Lime	1, 025-1, 031	Blue shale	2, 293-2, 308
Blue slate	1, 031-1, 150	Shale	2, 308-2, 318
Brown shale	1, 150-1, 320	Sand	2, 318-2, 322
Blue slate	1, 320-1, 360	Blue shale	2, 322-2, 327
Red rock	1, 360-1, 527	Shale	2, 327-2, 375
Sand; oil	1, 527-1, 530	Red rock	2, 375-2, 390
Brown shale and shells	1, 530-1, 550	Blue shale	2, 390-2, 458
Blue slate	1, 550-1, 557	Sand lime; water	2, 458-2, 472
Sand; gas	1, 557-1, 566	Blue shale	2, 472-2, 545
Brown shale	1, 566-1, 576	Lime	2, 545-2, 550
Sand shells	1, 576-1, 580	Blue shale	2, 550-2, 625
Blue slate	1, 580-1, 590	Brown shale	2, 625-2, 635
Red beds	1, 590-1, 600	Blue shale	2, 635-2, 690
Blue slate	1, 600-1, 620	Brown shale	2, 690-2, 733
Sand; water	1, 620-1, 630	Black lime	2, 733-2, 735
Blue slate	1, 630-1, 675	Lime	2, 735-2, 745
Sand; gas	1, 675-1, 695	Blue shale	2, 745-2, 760
Blue slate	1, 695-1, 830	Red rock	2, 760-2, 775
Sand shell	1, 830-1, 833	Blue shale	2, 775-2, 790
Red beds	1, 833-1, 870	Red rock	2, 790-2, 825
Blue slate, sandy	1, 870-1, 915	Blue shale	2, 825-2, 835
Red beds	1, 915-1, 930	Red rock	2, 835-2, 850
Blue slate	1, 930-1, 945	Blue shale	2, 850-2, 890
Red beds	1, 945-1, 965	Brown shale	2, 890-2, 900
Blue slate	1, 965-1, 985	Blue shale	2, 900-2, 910
Red beds	1, 985-2, 000	Blue sandy shale; gas	2, 910-2, 915
Blue slate	2, 000-2, 005	Blue shale	2, 915-2, 925
Soft sand; show of gas	2, 005-2, 011	Red rock	2, 925-2, 945

*Driller's logs of wells in Cement oil field, Caddo County, Okla.—Continued.*Cothlin well No. 19, Fortana Oil Co., northwest corner SE. $\frac{1}{4}$ sec. 35, Tenkawa Township—Con.

	Feet.		Feet.
Blue shale	2,945-2,980	Blue shale and shells	3,275-3,280
Brown shale	2,980-2,990	Brown shale	3,280-3,285
Blue shale	2,990-3,005	Sandy brown shale	3,285-3,315
Blue shale and shells	3,005-3,010	Brown shale	3,315-3,330
Red rock	3,010-3,020	Brown sandy shale	3,330-3,360
Blue shale	3,020-3,035	Blue sandy shale	3,360-3,365
Red rock	3,035-3,040	Lime	3,365-3,380
Blue shale	3,040-3,050	Blue sandy shale	3,380-3,400
Blue shale and shells	3,050-3,070	Blue shale	3,400-3,510
Brown shale	3,070-3,075	Blue sandy lime	3,510-3,520
Blue shale and shells	3,075-3,115	Sand; water	3,520-3,550
Brown shale	3,115-3,182	Sand	3,550-3,560
Blue shale	3,182-3,187	Sandy lime	3,560-3,570
Brown shale	3,187-3,190	Sand; showing of gas	3,570-3,572
Blue shale and shells	3,190-3,217	Blue shale	3,572-3,590
Sand; showing of oil	3,217-3,225	Lime	3,590-3,595
Blue shale	3,225-3,235	Brown shale	3,595-3,600
Brown shale	3,235-3,255	Lime shell	3,600-3,603
Blue shale and lime	3,255-3,260	Blue shale	3,603-3,620
Lime	3,260-3,270	Lime shell	3,620-3,625
Brown shale	3,270-3,275	Blue shale	3,625-3,640

Casing record: 20-inch, 150 feet; 15 $\frac{1}{2}$ -inch, 504 feet; 12 $\frac{1}{2}$ -inch, 1,057 feet; 10-inch, 1,784 feet; 8 $\frac{1}{2}$ -inch, 2,445 feet; 6 $\frac{3}{4}$ -inch, 3,206 feet; 5 $\frac{1}{8}$ -inch, 3,535 feet.

Davis well No. 1, Keeche Oil & Gas Co., sec. 1, Doyle Township.

[No. 30, Pl. XI. Completed May 14, 1919; initial production, 175 barrels a day.]

	Feet.		Feet.
Sand	0- 60	Sandrock	1,172-1,175
Sand and mud	60- 131	Gumbo	1,175-1,185
Clay	131- 142	Sand and shale	1,185-1,178
Sandrock	142- 147	Sandrock	1,278-1,310
Clay	147- 154	Shale	1,310-1,333
Sandrock	154- 219	Sandrock	1,333-1,343
Shale	219- 227	Shale	1,343-1,552
Sandrock	227- 231	Gumbo	1,552-1,582
Hard shale	231- 238	Sand and shale	1,582-1,610
Sand	238- 308	Packed sand	1,610-1,683
Shale	308- 318	Gumbo	1,683-1,704
Pack sand	318- 420	Sand	1,704-1,722
Shale	420- 430	Shale	1,722-1,795
Sand and pyrites	430- 531	Gumbo	1,795-1,813
Shale and boulders	531- 552	Sand, soft	1,813-1,830
Sandrock	552- 561	Shale	1,830-1,862
Sand and shale	561- 590	Sand	1,862-1,870
Hard sand and pyrites	590- 887	Shale and sand	1,870-2,075
Gumbo and pyrites	887- 903	Sandrock	2,075-2,068
Blue mud	903- 951	Shale and boulder	2,068-2,172
Sand and pyrites	951- 967	Lime and sand; oil	2,172-2,190
Red and blue mud	967-1,172	Gumbo	2,190-2,212

Driller's logs of wells in Cement oil field, Caddo County, Okla.—Continued.

Davis well No. 1, Keeche Oil & Gas Co., sec. 1, Doyle Township—Continued.

	Feet.		Feet.
Shale and lime shells.....	2, 212-2, 246	Red rock.....	2, 290-2, 317
Red shale.....	2, 246-2, 267	Lime.....	2, 317-2, 320
Rock.....	2, 267-2, 268	Red rock.....	2, 320-2, 324
Red rock.....	2, 268-2, 288	Sand; oil [Fortuna sand].....	2, 324-2, 354
Lime.....	2, 288-2, 290		

Paukune well No. 1, Gladstone Oil Co., sec. 3, South Cement Township.

(No. 48, Pl. XI. Completed in August, 1919; initial production, 150 barrels a day.)

	Feet.		Feet.
Soil.....	0- 5	Blue shale.....	1, 441-1, 469
Quicksand.....	5- 37	Red and blue shale, tough.....	1, 469-1, 570
Rock.....	37- 44	Very hard red sand.....	1, 570-1, 587
Hard red shale.....	44- 78	Red shale, hard and tough.....	1, 587-1, 620
Sand and shale.....	78- 92	Blue shale, hard and soft.....	1, 620-1, 643
Hard red sand.....	92- 146	Hard sandy shale and lime; gas showing.....	1, 643-1, 664
Hard blue shale.....	146- 265	Hard red and blue shale.....	1, 664-1, 677
Hard rock, granite.....	265- 269	Hard blue shale and sand.....	1, 677-1, 700
Hard blue shale and rock.....	269- 301	Pack sand.....	1, 700-1, 734
Hard rock.....	301- 304	Hard blue shale and sand.....	1, 734-1, 820
Blue shale.....	304- 406	Lime.....	1, 820-1, 823
Blue limerock.....	406- 408	Hard blue shale and pyrites.....	1, 823-1, 837
Blue shale.....	408- 472	Brown gumbo.....	1, 837-1, 842
Limerock.....	472- 475	Sandy blue shale.....	1, 842-1, 846
Hard blue shale.....	475- 600	Hard rock.....	1, 846-1, 848
Blue shale.....	600- 620	Blue shale and pyrites.....	1, 848-1, 859
White lime.....	620- 635	Blue shale and lime.....	1, 859-1, 894
Hard blue ——— and pyrites.....	635- 684	Blue rock.....	1, 894-1, 898
Hard blue sandy shale and pyrites.....	684- 696	Shale and gumbo.....	1, 898-1, 915
Hard blue shale and pyrites.....	696- 751	Shell rock.....	1, 915-1, 918
Sandrock and pyrites.....	751- 763	Shale and gumbo.....	1, 918-1, 922
Hard blue shale.....	763- 786	Sandrock.....	1, 922-1, 930
Hard and soft blue shale.....	786- 806	Blue shale.....	1, 930-1, 975
Hard blue shale.....	806- 821	Sandy shale.....	1, 975-1, 995
Hard shale and pack sand.....	821- 855	Soft shale.....	1, 995-2, 028
Hard and soft blue shale.....	855- 865	Hard shale.....	2, 028-2, 040
Small showing of gas.....	865- 910	Blue shale.....	2, 040-2, 060
Soft red and blue shale.....	910- 971	Blue and red shale and sand.....	2, 060-2, 092
Hard and soft red and blue shale.....	971-1, 080	Hard blue shale and brown sand.....	2, 092-2, 106
Hard blue shale.....	1, 080-1, 173	Blue shale.....	2, 106-2, 151
Hard red and blue shale.....	1, 173-1, 325	Red and blue shale and sand.....	2, 151-2, 196
Hard blue shale.....	1, 325-1, 340	Tough red shale.....	2, 196-2, 219
Oil showing.....	1, 340-1, 375		
Hard sand and shale.....	1, 375-1, 441		

*Driller's logs of wells in Cement oil field, Caddo County, Okla.—Continued.***Paukune well No. 1, Gladstone Oil Co., sec. 3, South Cement Township—Continued.**

	Feet.		Feet.
Hard blue shale.....	2, 219-2, 233	Red and blue shale and sand	2, 261-2, 299
Sandy shale; showing of oil and gas	2, 233-2, 244	Blue shale and sand.....	2, 299-2, 367
Hard sand; showing of oil and gas.....	2, 244-2, 255	Hard sand; oil and gas [Prosperity sand].....	2, 367-2, 400
Red sandy shale.....	2, 255-2, 261		

Headland well No. 1, McKinley Oil & Drilling Co., sec. 11, South Cement Township.

[No. 68, Pl. XI.]

	Feet.		Feet.
Hard sand.....	0- 55	Brown shale	730- 738
Hard shell.....	55- 67	Hard shale.....	738- 748
Soft shell.....	67- 70	Brown shale.....	748- 758
Hard shell.....	70- 76	Hard shale	758- 784
Soft sand.....	76- 80	Brown shale	784- 792
Hard shell.....	80- 88	Hard shell	792- 812
Water sand.....	88- 98	Blue shale.....	812-1, 000
Shell; set 12½-inch casing at 103 feet.....	98- 103	Red shale	1, 000-1, 050
Limestone	103- 115	Blue shale	1, 050-1, 100
Water sand.....	115- 125	Red shale	1, 100-1, 285
Hard shell.....	125- 140	Brown shale	1, 285-1, 325
Water sand.....	140- 142	Red shale.....	1, 325-1, 331
Hard shell.....	142- 146	Sandrock	1, 331-1, 350
Sandy shale.....	146- 176	Hard blue shale.....	1, 350-1, 402
Hard shell.....	176- 190	Shell	1, 402-1, 404
Soft shale	190- 197	Hard blue shale.....	1, 404-1, 430
Shell.....	197- 200	Gray shale	1, 430-1, 440
Blue shale.....	200- 210	Red shale	1, 440-1, 489
Hard shell.....	210- 217	Shell	1, 489-1, 490
Hard rock	217- 231	Blue shale.....	1, 490-1, 497
Blue shale.....	231- 281	Blue rock	1, 497-1, 509
Hard shell.....	281- 283	Blue shale	1, 509-1, 523
Hard shale	283- 310	Shell	1, 523-1, 525
Shale with thin shells...	310- 398	Blue rock	1, 525-1, 545
Blue shale.....	398- 485	Blue shale	1, 545-1, 551
Pyrites of iron.....	485- 497	Shell	1, 551-1, 553
Blue shale	497- 503	Blue shale.....	1, 553-1, 557
Hard and rough.....	503- 507	Shell	1, 557-1, 560
Blue shale.....	507- 515	Rock	1, 560-1, 580
Shell	515- 517	Slate and rock.....	1, 580-1, 594
Blue shale.....	517- 525	Blue rock	1, 594-1, 600
Brown shale and shells...	525- 590	Hard blue shale.....	1, 600-1, 689
Soft blue shale.....	590- 610	Lime	1, 689-1, 691
Shell	610- 612	Red shale.....	1, 691-1, 705
Soft brown shale.....	612- 667	Gray shale	1, 705-1, 730
Sandrock	667- 700	Gumbo	1, 730-1, 735
Hard shell	700- 707	Gray shale	1, 735-1, 782
Hard shale	707- 730	Gumbo	1, 782-1, 815
		Blue shale	1, 815-1, 835

Driller's logs of wells in Cement oil field, Caddo County, Okla.—Continued.

Headland well No. 1, McKinley Oil & Drilling Co., sec. 11, South Cement Township—Con.

	Feet.		Feet.
Gumbo	1,835-1,840	Shell	2,120-2,134
Blue shale	1,840-1,881	Blue shale	2,134-2,146
Blue gumbo	1,881-1,885	Red gumbo	2,146-2,170
Shell	1,885-1,891	Blue shale	2,170-2,212
Red gumbo	1,891-1,942	Shell	2,212-2,213
Blue shale	1,942-1,948	Red gumbo	2,213-2,235
Gumbo	1,948-2,030	Blue shale; setting 8½-	
Blue shale	2,030-2,070	inch casing at 2,321	
Gumbo	2,070-2,075	feet	2,235-2,321
Blue shale	2,075-2,120		

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DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 726—C

OIL PROSPECTS IN WASHINGTON COUNTY, UTAH

BY

HARVEY BASSLER

AND

JOHN B. REESIDE, JR.

Contributions to economic geology, 1921, Part II
(Pages 87-167)

Published August 15, 1921



WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

CONTENTS.

	Page.
Introduction.....	87
Geology.....	89
Stratigraphy.....	89
Structure.....	93
Oil prospects in the district east of the Hurricane fault.....	93
Field near Virgin City.....	93
Other favorable localities.....	97
Higher oil sand.....	98
Prospects for future production.....	98
Oil prospects in the district west of the Hurricane fault.....	99
Virgin anticline.....	99
Harrisburg dome.....	99
Washington dome.....	101
Bloomington dome.....	102
Fictitious "Kingman dome".....	103
Other anticlines.....	103
Evidences of oil.....	104
Ground water.....	105
Prospects of commercial production.....	105
Difficulties of prospecting.....	106
Recommendations for drilling.....	106

ILLUSTRATIONS.

	Page.
FIGURE 9. Map of parts of Washington County, Utah, and Mohave County, Ariz.....	88
10. Map of the oil field near Virgin City, Utah.....	94
11. Map of part of the Virgin anticline, Washington County, Utah, showing the Harrisburg and Washington domes.....	100
12. Map of the Bloomington dome, Washington County, Utah.....	103

OIL PROSPECTS IN WASHINGTON COUNTY, UTAH.

By HARVEY BASSLER and JOHN B. REESIDE, Jr.

INTRODUCTION.

Washington County is the extreme southwestern county of Utah. It is reached most easily by autostage from stations on the Los Angeles & Salt Lake Railroad. Most of the traffic of the county passes through Lund by way of Cedar City, a distance of 90 miles from St. George, the county seat; part of it passes through Modena by way of Enterprise, a distance of 60 miles but at present a more difficult route. An automobile route, the Arrowhead Trail, connecting Salt Lake City and Los Angeles, crosses the central part of the county. From this route spur highways reach the main towns and Zion Canyon National Park, in the eastern part of the county. Except on these main roads automobile traffic is somewhat hazardous—indeed, for the greater part impracticable. (See fig. 9.)

The region is drained by Virgin River, one of the larger tributaries of the Colorado, and might be considered the northern extension of the Grand Canyon district. Erosion has produced a topography of marked relief, and over much of the area rock exposures, which are common in the steep slopes and canyon walls and along the ridges, make it relatively easy to observe stratigraphic and structural details.

The climate is arid, and farming, except on the upland plateaus, is practicable only where streams supply water for irrigation. Such streams are absent south of Virgin River and are not numerous north of it, there being only five of six of any importance. The climate makes it possible in these favored localities to produce many varieties of fruit and other products, some of them semitropical, upon which the population of the region now depends largely for its support. Sheep and cattle raising is an important industry, the high plateaus and mountain pastures being occupied for this purpose in the summer and the lowlands in the winter.

St. George is the chief town and county seat. It has a population of 2,215 (1920), with the usual complement of stores, banks, and other enterprises necessary for the trading center of an agricultural region. Other towns are scattered along Virgin River and its principal tribu-

taries. Leeds, 15 miles east of St. George, was formerly the center of a prosperous silver-mining district, but the industry has been idle since the late nineties.

Exploratory drilling for oil has not been extensive in Washington County. Drilling near Virgin City resulted in several small wells as early as 1907. About 15 test wells were then sunk, most of them

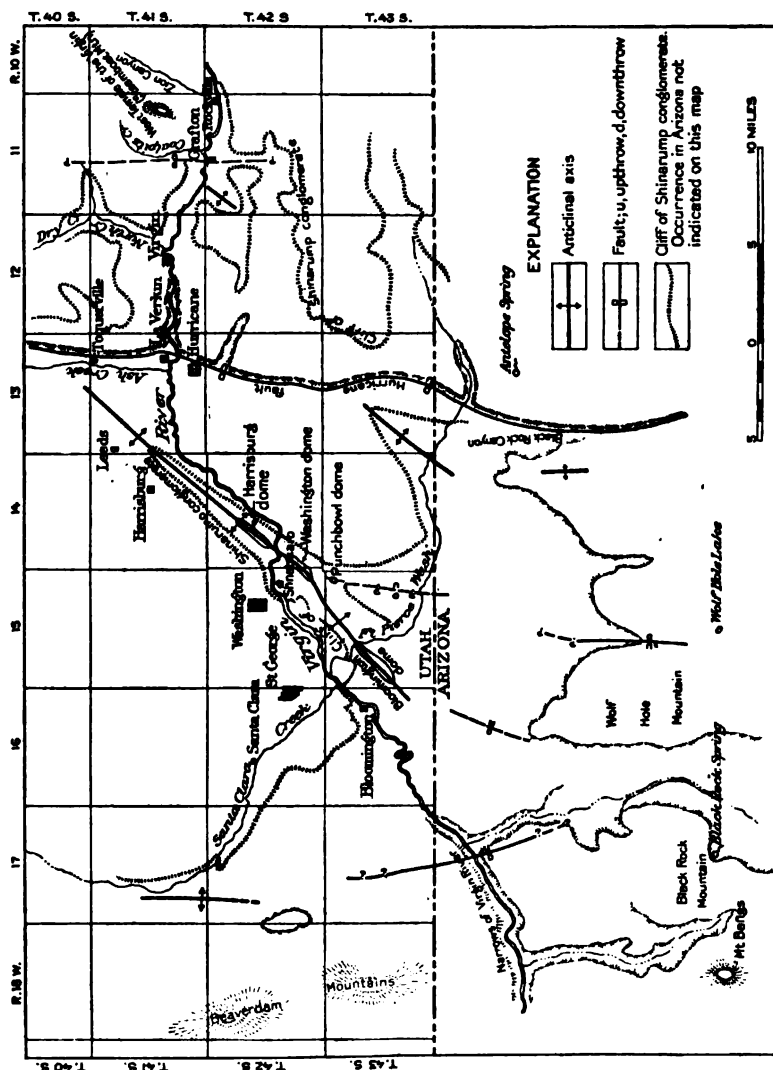


FIGURE 9.—Map of parts of Washington County, Utah, and Mohave County, Ariz.

grouped near Virgin City but some a considerable distance away. No further exploration was made for 10 years, when some of the old wells near Virgin City were cleaned out and several new wells were drilled. In 1919 a well was started on the Harrisburg dome and has reached a depth of 2,200 feet (September, 1920).

The writers spent part of the autumn of 1919 examining the region in reconnaissance. Some detailed work was done near Virgin City and on the three domes of the Virgin anticline, but much of the work was rapid, without a satisfactory base map, and accordingly lacks detail. Much assistance was given by several residents, for which the writers take this opportunity of expressing their thanks.

GEOLOGY.

STRATIGRAPHY.

The rocks of the region range in age from Mississippian to Tertiary, but those of greatest importance as possible sources of oil are the older rocks, beneath what is known as the Shinarump conglomerate—the relatively thin but resistant and sharply marked brown sandstone, bearing pebbles and many petrified logs, that forms an easily recognized and persistent cliff-making stratum over a large stretch of country. These older rocks are included in the Moenkopi formation, the Kaibab limestone, and a sandstone formation which represents the Coconino sandstone and Supai formation of the Grand Canyon area. The Moenkopi formation, of red sandstone, shale, and gypsum, with yellow earthy limestone in the lower part and a discontinuous conglomeratic limestone member at the base, was long believed to be of Permian age but is now considered Lower Triassic. It is from 1,800 to 2,000 feet thick in this region. The Kaibab limestone is at most points not a pure limestone formation but consists of two layers of very hard cherty gray limestone separated by softer shale, gypsum, and thin dark limestone. At many points the lower hard limestone is underlain by soft material similar to that above, and locally there is above the upper hard limestone a variable series of limestone, gypsum, and shale. The divisions vary much in thickness at different localities and may include beds at somewhat different horizons in the formation at different places. The entire formation ranges from 950 to 1,100 feet in thickness. In the past it has been considered of Pennsylvanian age, but it is now believed by many geologists to be Permian and is so classified by the United States Geological Survey.

Beneath the Kaibab limestone is a massive yellow and red sandstone containing, in the St. George district, very few soft or shaly layers and attaining 1,500 feet in thickness. Farther east it contains a larger proportion of shaly layers. In the Grand Canyon the Kaibab limestone is underlain by the Coconino sandstone, a light-colored massive formation 300 feet thick, of Permian (?) age, which rests on the Supai formation, a succession of red sandstone and shale about 1,200 feet thick, of Pennsylvanian (?) age. In the general region of St. George the rocks underlying the Kaibab do not possess the precise

characteristic features of the Coconino and Supai of the Grand Canyon, but examination of a series of stratigraphic sections at intervals between these regions has revealed a gradual northwestward thinning of the typical Coconino until its identity is finally lost in the top of the sandstone beneath the Kaibab limestone. This sandstone in the same direction becomes increasingly more sandy and less red until in the Beaver Dam Mountains, west of St. George, there is no longer any really red material nor any shale throughout its thickness of more than 1,400 feet. In Virgin Canyon a dense gray siliceous limestone lies beneath the sandstone and is probably equivalent to the Redwall limestone of the Grand Canyon, which is in part Pennsylvanian and in part Mississippian.

Composite section for the region east of the Hurricane fault scarp.

Smith's Mesa, 3 miles north of Virgin City, Utah.

Shinarump conglomerate (Triassic):		Feet.
Sandstone, gray, platy, with a few pebbles.		20
Shale, gray to green, with some fossil wood.		20
Sandstone, coarse, gray-white on fresh surface, limonitic brown on weathered surface; locally filled with small black blobs of wad in appearance suggestive of specks of petroleum; contains lenses of pebbles of chert, variously colored, quartz, silicified wood, and igneous rock. Base is irregular. Unit contains abundance of fossil logs, mostly silicified though in part replaced by copper minerals and rarely by pockets of lignite.		75
		115
Unconformity.		
Moenkopi formation (Lower Triassic):		
Sandstone, soft, and shale, brick-red to very deep red, with gypsum and a little lighter-colored shale.		405
Shnabkaib shale member: ¹ Shale, sandy, and sandstone, soft, fine grained, creamy white, with some pinkish layers and gypsum.		360
Sandstone and shale, brick-red, with some reddish gypsum and light bluish-gray gypsum; lighter colored than the upper red beds.		400
Virgin limestone member: ²		
Limestone, yellow, earthy, fossiliferous.		5
Shale, yellow and red.		25

¹ Named for the striking isolated mesa 2 miles southwest of the town of Washington, on the northwest flank of the Washington dome. This member is more fully described in a forthcoming report on the stratigraphy of the region, by the authors of this report, which will form one of the chapters of Professional Paper 129.

² The Virgin limestone member, Rock Canyon conglomeratic member, and Harrisburg gypsiferous member are new names, used for the first time in this report, but the members are more fully described in a forthcoming report on the stratigraphy of the region, by the authors of this report, which will form one of the chapters of Professional Paper 129. The Virgin limestone member is named for Virgin City, where the limestone is well exposed; the Rock Canyon member is named for Rock Canyon, 5 miles north of Antelope Spring, Ariz.; and the Harrisburg member is named for its occurrence in the Harrisburg dome, 8 miles east of St. George.

Moenkopi formation (Lower Triassic)—Continued.	Feet.
Virginia limestone member—Continued.	
Limestone, yellow, earthy, fossiliferous.....	5
Shale, yellow, calcareous.....	25
Limestone, fairly massive, yellow, earthy, fossiliferous	20
	80
Sandstone and shale, brick-red, with gypsum.....	360
Rock Canyon conglomeratic member: ² Irregular complex of limestone, limestone and chert conglomerate, shale, and gypsum. Absent locally.....	170
	1,775
Unconformity.	

Hurricane fault scarp, 6 miles south of Hurricane, Utah.

Kaibab limestone (Permian):

Harrisburg gypsiferous member ² (may include some beds of basal part of Moenkopi formation): Limestone, gray, thin bedded, some of it containing many small angular fragments of chert; and shale, gray or yellow.....	160
Limestone, massive, gray, with much brown chert; fossils abundant in chert; forms upper cliff.....	260
Shale, soft sandstone, and gypsum, the whole forming a gray slope.....	200
Limestone, gray, massive, with much brown chert; light colored on fresh surface; contains softer shaly layers near middle of unit; forms lower cliff.....	230
Limestone, sandy, cream-colored, and also thin bedded; dark drab; gypsum, white to gray; forms slope.....	80
	930

Black Rock Canyon, Ariz., 18 miles south of Hurricane, Utah.

Coconino sandstone (Permian?) and Supai formation (Pennsylvanian?):

Sandstone, medium grained, gray-white on fresh surface, yellow-brown on weathered surface, medium-bedded, cross-bedded.....	200
Sandstone, like unit above but in thinner beds separated by softer brick-red sandstone.....	490
Sandstone, medium grained, cross-bedded, gray-white on fresh surface, yellow-brown on weathered surface, relatively thin bedded and forming a bench.....	155
Sandstone, like the unit next above but practically in one bed and forming a sheer wall; exposed.....	380
	1,225

² See footnote 2 on page 90.

*Composite section for the region near St. George, Utah.***Harrisburg dome, 8 miles east of St. George.**

	Feet.
Shinarump conglomerate (Triassic).....	100±
Unconformity.	
Moenkopi formation (Lower Triassic):	
Shale and sandstone, brick-red; upper part very dark.....	320
Sandstone, yellow, medium grained; massive in upper part.	75
Shale, red, with some sandstone and gypsum.....	80
Shnabkaib shale member: Shale, sandy, white to light gray, with gypsum and some pink shale.....	630
Shale, red, sandy, with gypsum.....	435
Virgin limestone member: Limestone, earthy, greenish yellow, in three thin bands separated by greenish-yellow and reddish-brown shale.....	160
Shale, red, some of it sandy, with gypsum and a little bluish gypsiferous shale.....	275
Shale, yellow, gypsiferous.	60
Rock Canyon conglomeratic member absent at this local- ity, though present elsewhere in the region.	
	2,035

Unconformity.

Kaibab limestone (Permian):

Harrisburg gypsiferous member: Limestone, light gray, blue-gray, yellow, and reddish, some of it with very characteristic white chert with platy fracture; shale, red and yellow, gypsiferous; gypsum.....	137
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Narrows of Virgin River, below Bloomington, Utah.

Limestone, thin bedded, gray, with some small chert frag- ments; may duplicate some of Harrisburg member described above.....	70
Limestone, massive, uniform, fine grained, gray on fresh surface, brownish on weathered surface; filled with layers and nodules of brown chert.....	275
Breccia of limestone and chert in a limy matrix; whole mass weathers to a yellow-brown color. This unit with unit above forms a cliff.	110
Gypsum, red shale, breccia of limestone and chert, and gray shale, forming a slope.....	80
Limestone, very massive, gray to light gray on weathered surface, cherty; forms cliff.....	220
Soft sandstone, yellow, gypsiferous; limestone, thin bedded and arenaceous; forms slope.....	65
	957

	Feet.
Coconino sandstone (Permian?) and Supai formation (Pennsylvanian):	
Coconino sandstone(?): Sandstone, cross-bedded, buff, coarse, above; sandstone, white on fresh surface, dark gray on weathered surface, cross-bedded, in middle; sandstone, white to cream-colored, earthy, below.....	45
Supai formation(?): Sandstone, medium-grained, cross-bedded, exceedingly massive. Lower part yellow and brown with a little irregular red staining; middle part similar but with much red staining and a few thin soft red sandstones; upper part at some places a uniform red but usually a clean yellow-brown. The unit is practically one continuous bed and can not be divided into definite subunits.....	1,490
Redwall limestone (Pennsylvanian and Mississippian):	
Limestone, siliceous, with some sandstone; mostly heavy bedded; light gray on fresh surface, red-brown to dark gray on weathered surface; exposed.....	500

STRUCTURE.

The region may be considered structurally as two districts separated by the Hurricane fault, which runs north and south on a line 15 miles east of St. George. East of the fault the rocks are relatively little disturbed. Some smaller faults and some low anticlines are present, but as a whole the district is one of low monoclinal dips without any large modifications. This structure is expressed topographically by flat-topped mesas and level benches of hard strata with intervening slopes of soft materials. West of the Hurricane fault folds and smaller faults of various sizes have so greatly changed the original attitude of the rocks that the district is structurally complex in comparison with that east of the fault. A north-south fault of considerable size lies along the east side of Heber Valley, 10 miles west of St. George. Another 10 to 20 miles south of St. George, east of Wolf Hole Mountain, may be a northward extension of the Grand Wash fault of the earlier geologists, but it has not yet been traced more than a short distance.

OIL PROSPECTS IN THE DISTRICT EAST OF THE HURRICANE FAULT.

FIELD NEAR VIRGIN CITY.

Oil was discovered in 1907 at a point 2 miles northeast of Virgin City, in sec. 13, T. 41 S., R. 12 W., and for a short time exploration was very active. About 15 wells were drilled, most of them grouped around Virgin City but a few at some distance from it. According to the best information now available most of these wells were failures, making only small or no showings of oil and gas; one in

Virgin City is said to have produced enough gas to make a flame several feet long from a 2-inch pipe; one well (No. 9, fig. 10) produced some oil; and three wells, the present producers, came in with production stated variously as high as 36 barrels a day but probably in reality not more than half that.

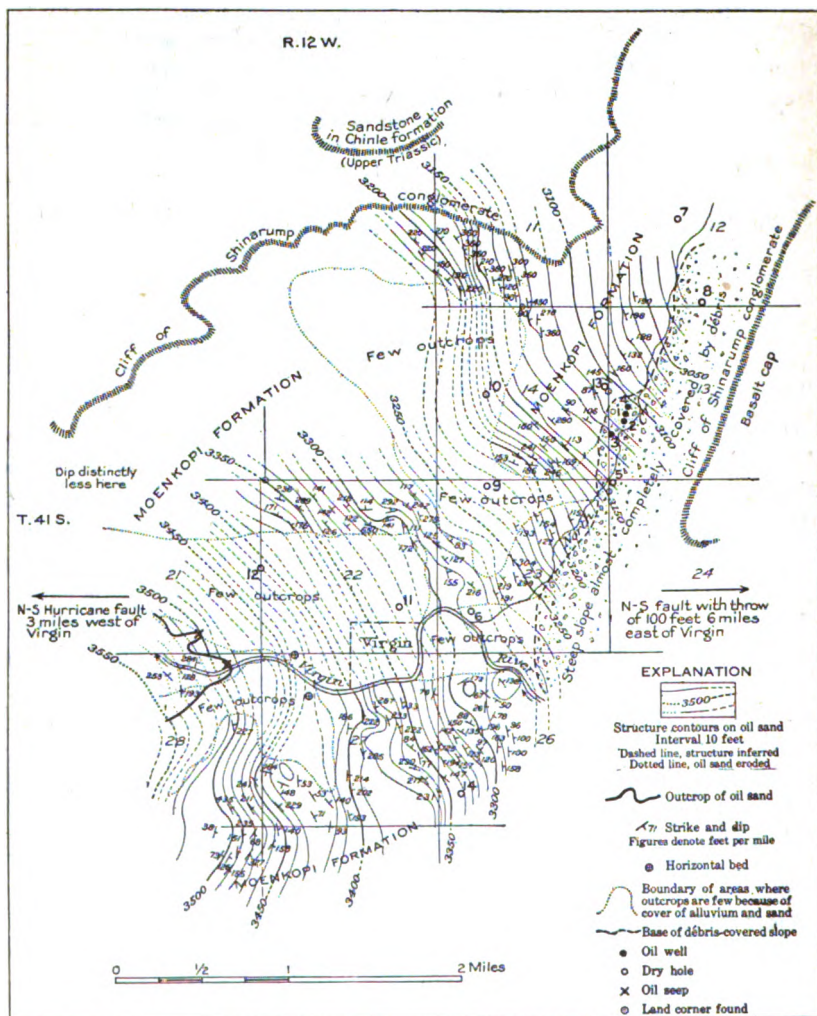


FIGURE 10.—Map of the oil field near Virgin City, Utah.

There was no market for the oil at the time of discovery except as fuel for further drilling, and as the financial panic of 1907 cut down the capital necessary for such exploratory work all activity ceased abruptly.

Nothing more was done in the field until 1918, when the three producing wells were cleaned out and shot, pumping was started, and a

small local refinery was built. A new well was drilled near the old wells and has a production of 4 or 5 barrels a day; a second hole put down on the north bank of Virgin River, about a mile south of the first one, proved to be dry. The total production from the four wells, which are uncased holes 550 to 600 feet deep, is about 20 barrels a day (September, 1920). The bulk of this amount is coming from one well, the other wells pumping much more water than oil. The refinery will handle 800 gallons of crude oil per 8-hour shift, and the products find a ready local market.

The oil is reported to range in gravity from 25° to 35° Baumé, to have a paraffin base that includes some asphalt, and to contain some sulphur. It is dark brown and very fluid. There has been little gas in the wells, but the amount is increasing as pumping continues.

The oil comes from a 1-foot bed of limestone which is at the top of the basal Rock Canyon conglomeratic member of the Moenkopi. The wells appear to have met no oil until they pierced this layer and to have obtained no increase from lower beds. This bed is easily found on the outcrop west of Virgin City, and at some points oil and sulphur water are seeping from it, notably at one locality a mile west of Virgin City. The associated limestone contains many cavities, due to the removal of fossils by solution, which are filled with a very fluid oil, though none is apparent in the mass of the rock. Likewise certain sandstone layers in the red beds of the Moenkopi above the limestone contain enough oil to form when fragments are heated in a glass tube a brown ring of oil on the cold part of the tube.

The original source of the oil has not been determined. No carbonaceous matter is apparent anywhere near the oil sand, either in the red beds above it or in the limestone beneath. Over a distance of perhaps 25 miles there is evidence locally of oil in the basal Moenkopi without any apparent carbonaceous matter in either the overlying or underlying rock. At this horizon some miles northeast of Toquerville there are in the limestone many fossil cavities filled with oil. This is true also at the places west of Virgin City mentioned above and at other localities 5 or 6 miles south of Virgin City. At the localities on Rock Canyon and 2 miles southwest of Black Rock Canyon, described on pages 104-105, the basal Moenkopi contains much asphaltic material. In the absence of any other probable source of the oil, the layers of abundantly fossiliferous limestone seem to be the most probable place of origin. However, the higher oil-bearing layer described on page 98 is separated by thick intervals of rock from any known fossiliferous beds.

The accumulation of oil may be due to various causes. In many fields an anticlinal fold is the governing factor, the oil accumulating in the higher parts of the fold if water is abundant in the sands, on the flanks if water is not abundant, and in the intervening synclines

if the rocks are dry. In other fields the oil accumulates in a rock terrace formed by a steplike wrinkle in an inclined layer. The dip is low on the terrace but steeper toward the terrace on the high side and away from it on the lower side. In some fields an inclined oil-bearing layer is sealed by faulting or by overlap at its upper end by impervious rocks, so that oil can accumulate just beneath the seal. Some oil reservoirs are merely porous pockets in rock that is elsewhere relatively impervious, as, for example, sandstone lenses in a shale. Or the rock may be more porous at some places than at others, permitting a greater oil content locally because there is more space for it. In some regions oil accumulates in the favorable places which are nearer the source of the oil and is absent from places that are equally favorable except that they are farther away. For example, in some large structural basins that contain folds at different distances from the basin rim oil moving up from the central part of the basin accumulates in the folds that lie nearer the center of the basin rather than in those that lie farther out.

The accumulation of oil in the field near Virgin City has been attributed previously either to the probable presence of permeable sandstone lenses in impervious shale or to chance variations in the porosity of a sandstone layer—causes neither of which is determinable from the surface. However, there is a much more probable cause of accumulation in the structure of the field. The rocks of this field dip to the northeast at an average angle of not more than 2° , though the dip is not uniform but is modified by steepenings where it may rise to 5° or 6° and by flattenings where the rocks are nearly level. The contour lines on figure 10 show the form of the surface of the oil sand, as nearly as it may be determined from the surface. Contour lines that are close together indicate that this surface is relatively steep; lines that are widely separated indicate that it is relatively flat. The producing wells, Nos. 1 to 4 of the map, in the SW. $\frac{1}{4}$ sec. 13, are clearly situated on a flat area. Well No. 5, in the NW. $\frac{1}{4}$ sec. 24, known to have been a failure, lies at the foot of an area of relatively high dip. Well No. 6, in the SW. $\frac{1}{4}$ sec. 23, known to have been a failure, seems to lie on a flat area, though near the higher edge. Well No. 9, in the NW. $\frac{1}{4}$ sec. 23, reported to have been a small producer, lies apparently on a flat. Well No. 11, in the SW. $\frac{1}{4}$ sec. 22, a gas well in Virgin City, may lie on a flat, though the contour lines for the area near it are based on insufficient data. The information now available, though it is not very reliable, seems to indicate that wells Nos. 7 and 8, in sec. 12; No. 10, in the NW. $\frac{1}{4}$ sec. 14; No. 12, near the west quarter corner of sec. 22; No. 13, near the west quarter corner of sec. 13; and No. 14, in the SW. $\frac{1}{4}$ sec. 26, were all failures. It seems most probable on the evidence here presented that terraces, or areas of low dip, are favorable to the accumulation of oil in this

field and that the steep slopes are unfavorable. To what extent, in addition, variations in porosity of the sand are a factor it is difficult to say, though they are probably of minor importance. There are no anticlines, faults, or other features closely enough associated with the producing field to offer an explanation for the accumulation of oil, so that the only likely factor left is that of accumulation on a terrace.

OTHER FAVORABLE LOCALITIES.

If the view above set forth is correct, there are several untested localities near Virgin City that are structurally as favorable at least as the small area from which oil is now obtained, and the producing wells are sufficiently close to these terraces to justify the recommendation that other localities where the structure is similar be tested. Approximate locations for such tests are the northwest corner of the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 23, T. 41 S., R. 12 W.; the center of the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 23, T. 41 S., R. 12 W.; the center of the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 26, T. 41 S., R. 12 W.; the center of the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 26, T. 41 S., R. 12 W.; and the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 27, T. 41 S., R. 12 W.

If drilling at these places gives favorable results, a still more pronounced flattening in the W. $\frac{1}{4}$ sec. 27, T. 41 S., R. 12 W., should be tested, though it lies so close to the outcrop of the oil-bearing beds that seepage at the outcrop may have allowed any oil present to escape, and it may not prove any better than the other locations. On the other hand, several fields lately brought in, such as the Upton-Thornton and Osage fields of Wyoming, produce from sands whose outcrop lies very close to the wells, and it is possible that a similar condition exists here.

A relatively pronounced structural terrace is visible on Virgin River 1 mile west of Grafton and 6 miles east of Virgin City, in secs. 5, 6, and 7, T. 42 S., R. 11 W. Old Grafton Wash cuts through it. The surface rock is the middle red-bed member of the Moenkopi formation. The fold trends northeast and southwest from the river. The dip on the southeast side is 6° to 8° SE., and the northwest side is flat or even slightly reversed. Farther northwest the low regional dip of about 2° SE. again prevails. This terrace is a duplicate on a somewhat larger scale and with more pronounced features of those near Virgin City. Under it the horizon of the producing sand at Virgin City lies at a depth of 800 to 900 feet. The locality where this terrace crosses San Juan River is only a mile west of the fault that passes in a north-south direction through Grafton. (See fig. 9.) Though toward the south the terrace diverges from the fault, the effect of the fault would be to cut down the area of rock that might contribute to a possible accumulation of oil on the terrace. A short distance north of San Juan River the fold passes under basalt and can not be traced farther, though it can not extend far before meeting

the fault. South of the river its full extent is not known, but it can be seen for several miles at least. The large size and apparent great extent of this fold in comparison with that producing at Virgin City make it worth a test.

Several miles east of Antelope Spring, Ariz., and about 20 miles south of Virgin City, where the general dip is 1° - 2° NE., a reversed dip of 1° - 3° W. in the Virgin limestone member of the Moenkopi formation betrays the presence of a low anticline whose axis extends apparently in a north-south direction. A reversed dip of 3° observed about 7 miles southeast of Antelope Spring probably indicates a southward extension of the axis to that locality. Little is known of the extent and character of this fold, as no study was made to determine its possibilities or select drill sites, but it is believed that its axis passes approximately through what would be sec. 19, T. 44 S., R. 12 W., if the Utah land subdivisions were extended into Arizona. The depth on this fold to the horizon of the sand that is productive at Virgin City should be 300 to 400 feet. A well drilled in 1907 about 4 miles east of Antelope Spring does not lie near enough to test this anticline, though it is said that gas was struck in the well.

HIGHER OIL SAND.

Another possible oil-bearing bed is in the upper part of the Moenkopi formation, in the midst of red beds, about 1,000 feet above the oil-yielding bed of the Virgin River field. This oil-bearing zone was noted on Dry Creek, 3 miles north of the Dixie Co.'s wells, where a 6-foot layer of brown sandy shale that smells strongly of oil when broken is overlain by 4 feet of contorted oil-stained shale containing nodules of gypsum. About 2 feet higher a 6-inch layer of shale and gypsum is crossed by stringers of pure black asphalt a quarter of an inch to an inch thick. Nothing was observed that would suggest the source of this oil and asphaltic matter. No carbonaceous material or fossils were seen in any of the beds above it up to the Shinarump conglomerate, and no carbonaceous matter or fossils occur between it and the Virgin limestone member. The containing beds themselves seem to include nothing that could have furnished oil. Where the structure is favorable and these beds lie 200 feet or more below the surface, they may be of greater value than the lower producing beds of the Virgin River field. Furthermore, wells sunk in such locations may reach down to the lower beds. No search was made by the writers to locate folds in the beds above this higher zone of oil-bearing rock, nor was it traced farther than the canyon of Dry Creek.

PROSPECTS FOR FUTURE PRODUCTION.

The present Virgin City field appears to be of value for supplying local demand. The thinness of the oil "sand" seems to preclude the

possibility of production adequate to repay the expenses of distributing the oil to refineries outside the field. However, at some distance from Virgin City the oil-bearing beds may thicken so much that they will furnish an adequate reservoir for greater accumulations of oil. Therefore any pronounced anticlinal fold that may be detected in the beds of the Moenkopi formation in this general region should be prospected to test this possibility.

OIL PROSPECTS IN THE DISTRICT WEST OF THE HURRICANE FAULT.

The most prominent structural feature of the district west of the Hurricane fault is the Virgin anticline, with its three superimposed domes—the Harrisburg dome, the Washington dome, and the Bloomington dome. Minor anticlines were noted at several localities.

VIRGIN ANTICLINE.

The axis of the Virgin anticline trends southwestward through Tps. 41 and 42 S., R. 14 W., and T. 43 S., R. 15 W. Over most of its length this anticline exposes the red rocks of the Moenkopi formation, but at three places, where it has been affected by cross folds, it brings up the Kaibab limestone. These cross folds form well-defined domes, called the Harrisburg, Washington, and Bloomington domes. The Harrisburg dome lies in secs. 8, 9, 16, and 17, T. 42 S., R. 14 W., about 3 miles east of the town of Washington. The Washington dome lies in secs. 30 and 31, T. 42 S., R. 14 W., and secs. 25 and 26, T. 42 S., R. 15 W., several miles southwest of the Harrisburg dome and southeast of the town of Washington. The Bloomington dome lies in secs. 8, 9, 17, 18, and 19, T. 43 S., R. 15 W., 6 miles southwest of the Washington dome and 5 miles south of the town of St. George. These three domes offer the most promising locations for the accumulation of oil if any is present in the anticline, and more time was spent in studying them. They are therefore described in some detail below, and the maps (figs. 11 and 12) show more detail than was procured regarding the other folds of the region.

Harrisburg dome.—The Harrisburg dome lies in secs. 8, 9, 16, and 17, T. 42 S., R. 14 W., just north of the place where Virgin River crosses the anticline, about 8 miles northeast of St. George and 3 miles east of Washington. An almost completely encircling outcrop of the Virgin limestone low in the Moenkopi formation and the high core of Kaibab limestone rising out of the red shales and sandstones mark it off, even to the layman's eye. The oil-bearing zone of Virgin City is not present over the crest of the dome and appears to be lacking also on the flanks. The dips are high, from 40° to 65°, and the folding is close—so close, in fact, that on the southeast flank a hinge fault has been formed on a line running 500

to 800 feet from the axis and parallel to it. (A hinge fault is a fault or crack starting in unbroken rock and gradually separating the broken ends of a given stratum farther and farther as it recedes

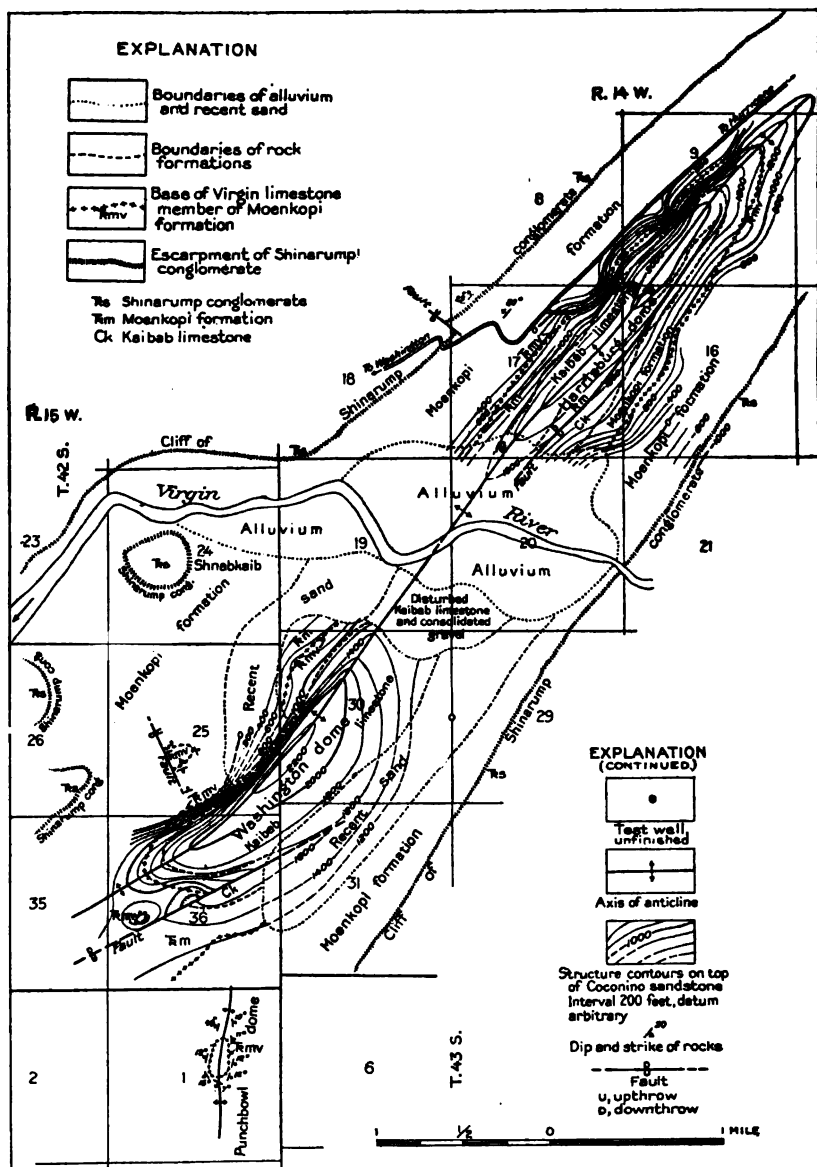


FIGURE 11.—Map of part of the Virgin anticline, Washington County, Utah, showing the Harrisburg and Washington domes.

from the unbroken part, somewhat as the two blades of an open pair of shears separate progressively outward from the pivot.) This fault begins near the north end of the dome, and the displace-

ment increases southward until the rocks on the east are raised a distance of perhaps 500 feet at the southernmost exposure. The Kaibab limestone is only slightly eroded at the top of the dome, and practically its entire thickness must be pierced to reach the sandstone. As the thickness is over 900 feet in the Hurricane cliff, to the east, and in Virgin Canyon, to the west, it is likely that 950 feet is not an excessive estimate of the thickness under the dome. Reports of the rocks passed through in drilling the well on this dome seem to indicate that they included a little more than 1,000 feet of Kaibab strata. This larger figure may be due to a thickening along the crest of the fold produced during the folding.

This well, the only well now being drilled in the region, is near the northwest corner of sec. 16 and is close to the highest point structurally on the Harrisburg dome. It lies practically on the axis and is an adequate test of the upper part of the dome. At present (September, 1920) the well is reported to have reached a depth of 2,200 feet and therefore to have pierced the Kaibab limestone and most of the underlying sandstone. It is proposed to continue the well to a greater depth, but the prospect of success at lower horizons is very small. A light showing of oil was reported at approximately the horizon of the top of the sandstone, and water was found at several other horizons.

Washington dome.—The Washington dome lies across Virgin River from the Harrisburg dome, in secs. 30 and 31, T. 42 S., R. 14 W., and secs. 25 and 26, T. 42 S., R. 15 W. It is separated from the Harrisburg dome by an area where bedrock is concealed by river silt, gravels, and blown sand, but there is ample field evidence that the two domes are distinct. South of the river some evidence of faulting is shown by small outcrops of much disturbed Kaibab and Moenkopi rocks piercing this mantle, but this faulting is on a small scale and does not affect the dome itself. The dome shows topographically in the high core of Kaibab limestone rising from the softer and more eroded red rocks of the Moenkopi formation. The Virgin limestone member of the Moenkopi formation is exposed locally but is mostly buried under blown sand. The oil-bearing bed of the Virgin City field is not present over the crest of the dome and where present on the flanks shows no indication of oil. The best chance of finding oil in this dome is in the sandstone that represents the Coconino and Supai formations. The Kaibab limestone is not deeply eroded on the crest of the fold, and any well would have to pierce most of that formation to reach the sandstone beneath, the thickness being the same as under the Harrisburg dome—that is, 900 to 1,000 feet of Kaibab limestone must be penetrated. The Washington dome is unsymmetrical. The dips on the west side are from 40° to 60° or more, and those on the east side are com-

monly around 20°; the axis therefore lies much closer to the west side. Near the south end of the dome a fault of the same type as that in the Harrisburg dome cuts the southeast flank, but it seems to be of lesser extent, though the displacement reaches 700 or 800 feet at its visible maximum. This fault is exposed for a distance of three-quarters of a mile and passes under cover at each end of the exposure. The structurally highest part of the dome lies at the surface in the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 30, T. 42 S., R. 14 W., and the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 25, T. 42 S., R. 15 W., but owing to the unsymmetrical form any drilling to test the crest should be shifted 300 to 400 feet to the east, as in such folds the axis does not lie in depth immediately beneath its position at the surface.

Several minor domes occur near the Washington dome. One of them lies north of the south end, near the center of sec. 25, T. 42 S., R. 15 W., and is cut by a small fault on the west side. Another lies south of the south end of the Washington dome, near the west side of sec. 36, T. 42 S., R. 15 W. A more pronounced minor dome is that in sec. 1, T. 43 S., R. 15 W., known locally as the Punchbowl dome. It is a true dome, though much smaller than the three main domes. These minor domes are all in the Moenkopi formation and are shown clearly by the attitude of the light-colored Virgin limestone member in the midst of the darker-colored red beds. In all these smaller domes the horizon of the oil sand of the Virgin City field, judged by the outcrops on the main dome, is either absent or is barren of oil if present. The depth to the Coconino-Supai sandstone is about 1,400 feet in each of the domes. These smaller domes are less favorable locations for drilling than the larger ones, which should be tested first.

Bloomington dome.—The Bloomington dome, which is larger than the other two chief domes, extends through secs. 8, 9, 17, 18, and 19, T. 43 S., R. 15 W., about 5 miles south of St. George. (See fig. 12.) It is clearly defined by the encircling Virgin limestone member of the Moenkopi and the high core of Kaibab limestone. The oil-bearing bed of the Virgin City field is not present over the crest of the dome and contains no oil where present on the flanks. The best chance of finding oil is in the Coconino-Supai sandstone. Like the Washington dome, this dome is unsymmetrical, the western flank dipping 40° to 70° and the eastern flank less than 20°. On it are imposed several distinct high areas, so that it is really a close group of domes. The largest, areally, of these subordinate domes is at the south end of the main dome, its crest lying in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ and NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 19. It is broader and more nearly symmetrical than the others. The oldest rock exposed is practically the top of the Kaibab limestone, and 900 to 1,000 feet of rock must be penetrated to reach the sandstone. The next largest crest is that in the SE. $\frac{1}{4}$

SE. $\frac{1}{4}$ sec. 8. It brings to the surface the top of the upper hard limestone of the Kaibab, and therefore a shallower well, about 800 feet deep, would reach the sandstone. It is smaller than the southern minor dome. Between these two is a smaller and lower high area, on the line between the NE. $\frac{1}{4}$ and the NW. $\frac{1}{4}$ sec. 17.

On the flank of the Bloomington dome in the SE. $\frac{1}{4}$ sec. 17 a minor dome has been formed. The surface rock is the Moenkopi formation beneath the Virgin limestone member. Another minor fold is present in the SW. $\frac{1}{4}$ sec. 19, on the east flank of the main dome.

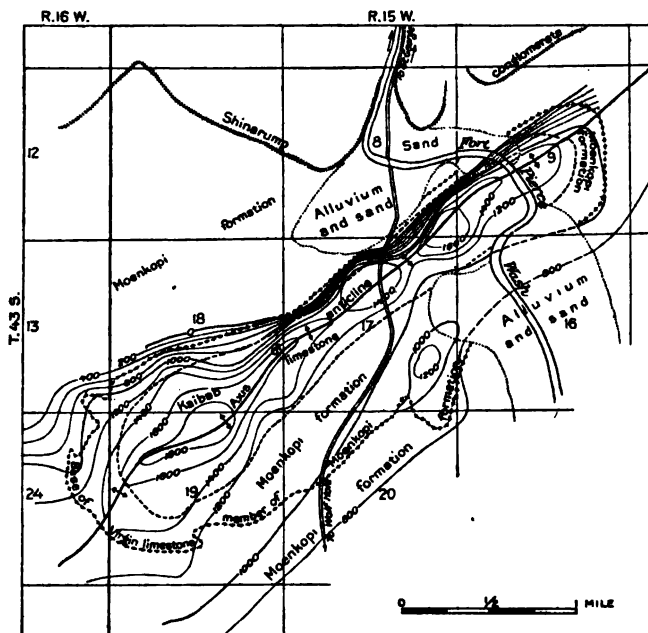


FIGURE 12.—Map of the Bloomington dome, Washington County, Utah.

Fictitious "Kingman dome."—South and southwest of the Bloomington dome a very large, relatively flat area is reported locally to be occupied by what is termed the "Kingman dome." There is no such dome, however, but in the area it is supposed to cover there are merely several very small domes.

OTHER ANTICLINES.

Smaller anticlines are present at several other places in this field. One of these extends through the eastern part of T. 41 S., R. 17 W., and is plainly shown where the Arrowhead Trail, the tourist route from St. George, Utah, to St. Thomas, Nev., crosses it, about 15 miles from St. George. The rocks exposed here are in the upper part of the Moenkopi formation. The axis of the fold trends nearly north and south and plunges to the north, and the dip of the flanks

is gentle. No study was made of this fold to determine its size or the presence of closed structure, but its axis extends 4 or 5 miles at least and is probably much longer. The oil-bearing zone of Virgin City may be present beneath it, and the Coconino-Supai sandstone is certainly there. At the locality where the Arrowhead Trail crosses the axis the former should lie about 1,500 feet beneath the surface and the latter about 2,500 feet. In the western part of T. 43 S., R. 13 W., about 15 miles south of east of St. George, another anticline, in rocks of the Moenkopi formation, extends in a northeasterly direction, the north end abutting against the Hurricane fault and the southern part passing over into Arizona. The axis of this fold plunges northeastward. The southeast limb dips steeply and is cut off obliquely by the fault. No detailed study was made of this fold, and its full extent and character are not known, but the axis extends at least 5 miles and is probably much longer. The Virgin City oil sand may be present beneath it, and the Coconino-Supai sandstone certainly is. The depth to these beds varies because of the plunging of the axis.

Farther south, in Arizona, at a place about 18 miles south of the town of Hurricane, Utah, and the same distance southeast of St. George, a small, low anticline with its axis trending north a mile west of the Hurricane fault is seen in rocks of the upper part of the Moenkopi formation. This fold is several miles in length and apparently closed. Its east limb is cut off by the Hurricane fault, but the west limb is not faulted so far as known. The Virgin City oil sand may be present beneath it, and the Coconino-Supai sandstone certainly is. Near Black Rock Spring, Ariz., 25 miles south of St. George, the valley between Black Rock Mountain and Wolf Hole Mountain contains a large number of small domes, the largest of them perhaps 3,000 feet across. These are in the lower part of the Moenkopi and the upper part of the Kaibab formation, but they are so numerous and so closely crowded together that their value is likely to be small. No detailed study was made of this area.

EVIDENCES OF OIL.

Evidence of oil in the rocks of this region is meager. The bed that furnishes the oil found at Virgin City is missing at the crests of the larger uplifts and if present elsewhere does not offer any indication of containing petroleum. The extreme top of the sandstone formation, where exposed in the Hurricane fault scarp 5 to 7 miles south of Hurricane, is stained along the face with oil, and the rock yields oil when heated in a glass tube. At a point 6 miles south of Hurricane this zone includes the upper 20 feet of the sandstone. Near Black Rock Canyon, Ariz., which lies 18 miles south of Hurricane, Utah, and is a distinct locality from Black Rock Spring, mentioned

above, thin zones at several horizons are stained by oil. However, the sandstone as exposed in the canyon of the Virgin below St. George shows no sign whatever of oil. In Rock Canyon, which cuts the Hurricane fault scarp about 15 miles south of Hurricane, a deep, wide gash was eroded into the upper part of the Kaibab limestone and filled with gypsum, shale, and limestone of the basal part of the Moenkopi formation. This filling is very irregular in composition and contains many thin veins of asphaltite and zones impregnated with bituminous matter. The material is more abundant in the lower part of the exposure and seems to have come up from below. About 2 miles west of the south end of Black Rock Canyon, in Arizona, a crushed zone, 100 feet wide, cutting through the lower part of the Moenkopi formation is filled with bituminous material in the form of veins and impregnations. This material likewise seems to have come up from below. These occurrences are favorable to the presence of oil in the suitable structural forms of the region in that they show at near-by points oily materials in rocks whose continuation underlies the folds, though they are by no means a proof that oil occurs in the folds.

GROUND WATER.

The water conditions in the older rocks of the region are but poorly known. Springs are rare, and as far as surface indications are valid the rocks seem to be dry. However, Virgin River crosses the outcrops of all the formations, and some water from this stream may seep into the rocks. Besides this the region has some rainfall, though small, and some of it must enter the rocks. In the well on the Harrisburg dome water was struck between 1,000 and 1,100 feet beneath the surface. It will probably be found at most points that the rocks below the surface contain water, a factor of great importance in the development of an oil field, for if water is present in abundance the highest parts of the anticlines and domes will usually contain any oil that may have accumulated.

PROSPECTS OF COMMERCIAL PRODUCTION.

The value of this region as a possible producer of oil it is impossible, of course, to gauge in advance of drilling. The region contains favorable structural features, and there are rocks in them capable of serving as reservoirs for oil. At certain places, as described above, there is evidence favorable to the assumption that these rocks carry some oil. Whether oil is actually present in these rocks in the anticlines and domes remains for the drill to determine. The well drilled on the Harrisburg dome is a fair test of a part of that fold. The fault on the east side, however, reduces the value of this test as a criterion for the region. However, no seepage along the fault is evident, and its largest effect is probably that of cutting off part

of the area of rock which might have contributed to any oil content of the dome. According to reports the drill penetrated 1,050 feet of limestone and about 1,200 feet of the Coconino-Supai sandstone without finding more than a light showing of oil. Failure of the well on this dome should not be taken as an absolute condemnation of the whole area, for the fault may have affected the dome adversely, whereas the other domes are still intact. Besides, if the rocks are only partly saturated with water oil may be absent on the crest and still be present down the dip. Nevertheless the crests of the domes should be tested first to determine the presence or absence of oil or water, before other locations are tried.

DIFFICULTIES OF EXPLORATION.

Drilling operations in Washington County, Utah, and the part of Arizona adjacent to it are in general carried on under some handicaps. No part of the region is less than 70 miles from a railroad by any practicable route, and much of it is 90 or 100 miles from a railroad. Much of the material for drilling must be brought from Los Angeles, Calif., or other distant center of supply. Away from a few main routes, such as that between Lund and St. George or that through Virgin City up the Virgin to Zion Canyon, the roads are mostly unkept trails. Fuel and water are expensive and hard to obtain at many localities. Electric power was used at the well on the Harrisburg dome but probably could not be supplied to many rigs at one time nor at places far from the transmission lines. The rocks of the Moenkopi formation are relatively soft and easy to drill, but those of the Kaibab limestone offer difficulties because of the abundance of chert, and drilling in them is slow and expensive.

RECOMMENDATIONS FOR DRILLING.

The localities near Virgin City suggested on page 97 as favorable places for drilling test wells lie near good roads and are easily accessible. Water in abundance may be obtained from ditches, from North Creek, or from Virgin River. Fuel is scarce, however, as the easily accessible timber has already been cut off, and coal, if used, must be hauled from Colob Plateau, some 30 miles to the north. Electric power is not now available in this district. The rocks to be drilled are relatively soft and offer little difficulty. Wells less than 600 feet deep should be sufficient.

Any test hole on the terrace near Grafton, described on page 97, should be located some distance south of Virgin River, perhaps in sec. 7, T. 42 S., R. 11 W., to get as far from the Grafton fault as possible. This locality would not be as easy of access as those near Virgin City, as the river would have to be forded and a road made to the south. Water could be piped or hauled from the river, but

fuel would have to be hauled a long distance. The rocks to be penetrated are relatively soft and easily drilled, and a 900-foot well should reach the horizon of the Virgin City oil sand.

The anticline east of Antelope Spring is not well enough known to justify the recommendation of localities for drilling. The rocks to be pierced are relatively soft and easy to drill, and water can be obtained from Antelope Spring, but the region is remote from the settlements and sources of supply, and fuel is scarce and must be hauled some distance.

The writers believe no further test should be made on the Harrisburg dome at present, at least not until showings elsewhere on the Virgin anticline justify it.

The first test on the Washington dome should be made near the northwest corner of the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 30, T. 42 S., R. 14 W. This locality is not easily accessible because of its high elevation and the rough topography, but a short road can be built to it from existing trails. Water can be obtained by piping or hauling from Virgin River. Fuel is very scarce and would have to be hauled a long distance unless electricity could be obtained to replace it. The use of electricity would entail the building of several miles of power line. The depth to the sandstone beneath the Kaibab limestone is 900 to 1,000 feet, and much of the rock is very cherty, tough material that is difficult to penetrate.

The first test on the Bloomington dome should be made near the center of the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 19, T. 43 S., R. 15 W. Conditions are much the same here as on the Washington dome except that the locality is more accessible. Water can be procured from ditches or from Fort Pierce Wash, but fuel is lacking. The depth to the sandstone is 900 to 1,000 feet, and the intervening rock is in large part tough and cherty. The second best locality on the Bloomington dome is in the southeastern part of the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 8, T. 43 S., R. 15 W. Here the depth to the sandstone is about 800 feet.

The minor domes near the Washington and Bloomington domes should not be tested unless the larger domes show good results or give some indication that there is oil down on the flanks which might be present in the smaller domes.

The anticlines described briefly on pages 103-104 need further examination. The present data are insufficient to determine the presence or absence of closure, and without this knowledge recommendations are unwarranted.

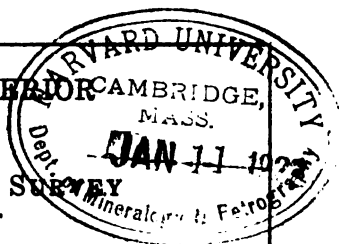


DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director



BULLETIN 726—D

**LIGNITE IN THE WESTERN PART OF THE
FORT BERTHOLD INDIAN RESERVATION
SOUTH OF MISSOURI RIVER
NORTH DAKOTA**

BY

CLYDE MAX. BAUER

AND

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Contributions to economic geology, 1921, Part II

(Pages 109-172)

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CONTENTS.

	Page.
Introduction.....	109
Importance of lignite.....	109
Location of field and scope of report.....	109
Field work and acknowledgments.....	109
Method of field work.....	110
Land surveys.....	111
Geography.....	111
Land forms.....	111
Drainage.....	112
Settlement.....	113
Geology.....	113
Stratigraphy.....	113
Quaternary system.....	114
Alluvium.....	114
Glacial drift.....	114
Tertiary system.....	114
Fort Union formation.....	114
General character.....	114
Fossils.....	116
Clinker.....	117
Structure.....	117
Origin of the coal-bearing formation.....	118
Lignite.....	119
Physical properties.....	119
Chemical character.....	119
Quantity.....	125
Distribution.....	126
Development.....	127
Lignite beds.....	128
Township descriptions.....	129
T. 152 N., R. 93 W.....	129
T. 152 N., R. 94 W.....	130
T. 152 N., R. 95 W.....	131
T. 151 N., R. 93 W.....	132
T. 151 N., R. 94 W.....	132
T. 151 N., R. 95 W.....	134
T. 150 N., R. 91 W.....	135
T. 150 N., R. 92 W.....	135
T. 150 N., R. 93 W.....	136
T. 150 N., R. 94 W.....	137
T. 150 N., R. 95 W.....	139
T. 149 N., R. 91 W.....	140
T. 149 N., R. 92 W.....	141
T. 149 N., R. 93 W.....	143
T. 149 N., R. 94 W.....	144

Township descriptions—Continued.

	Page
T. 149 N., R. 95 W.....	145
T. 148 N., R. 91 W., north of Little Missouri River.....	145
T. 148 N., R. 92 W.....	146
T. 148 N., R. 93 W.....	148
T. 148 N., R. 94 W.....	150
T. 148 N., R. 95 W.....	150
T. 147 N., Rs. 92 and 93 W., west of Little Missouri River.....	151
T. 147 N., R. 94 W.....	153
T. 147 N., R. 95 W.....	154
T. 147 N., R. 92 W., east of Little Missouri River.....	154
T. 146 N., R. 92 W.....	159
T. 148 N., R. 91 W., south of Little Missouri River.....	162
T. 147 N., R. 91 W.....	162
T. 146 N., R. 91 W.....	165
T. 147 N., R. 90 W.....	166
T. 146 N., R. 90 W.....	167
T. 147 N., R. 89 W.....	168
T. 146 N., R. 89 W.....	169
T. 147 N., R. 88 W.....	170
T. 146 N., R. 88 W.....	171

ILLUSTRATIONS.

	Page
PLATE XIII. A, "Breaks" of the Little Missouri, looking southeast toward the mouth of Hans Creek, N. Dak.; B, A thick bed of lignite in the Fort Berthold Indian Reservation, N. Dak.....	112
XIV. A, Badlands in sec. 26, T. 147 N., R. 93 W., N. Dak.; B, Badlands in sec. 25, T. 147 N., R. 93 W., N. Dak.....	113
XV. A, Missouri River, N. Dak., as seen from the upper margin of the badlands, looking north; B, Valley of Moccasin Creek near its mouth, in sec. 6, T. 147 N., R. 92 W., N. Dak.....	114
XVI. Stratigraphic sections in Fort Berthold Indian Reservation, N. Dak., showing correlation of coal beds.....	128
XVII. Sections of lignite beds in the northern part of the Fort Berthold Indian Reservation, N. Dak.....	132
XVIII. A, Bare buttes of the Fort Union formation on the south side of Hans Creek, N. Dak.; B, Log concretions in Fort Union formation.....	140
XIX. A, Glacial boulders on the upland in T. 147 N., R. 93 W., N. Dak.; B, Bed of lignite 8 feet thick in natural exposure in sec. 14, T. 147 N., R. 93 W., N. Dak.....	141
XX. Sections of lignite beds in the northern part of the Fort Berthold Indian Reservation, N. Dak.....	144
XXI. A, Fossil log standing nearly upright in clay shale of the Fort Union formation; B, Fossil stump in Fort Union formation.....	152

	Page.
PLATE XXII. <i>A</i> , Sage-brush flat of Hans Creek, N. Dak., and bluffs of the Fort Union formation; <i>B</i> , Rolling upland in the Fort Berthold Indian Reservation, N. Dak.-----	153
XXIII. Sections of lignite beds in the southwestern part of the Fort Berthold Indian Reservation, N. Dak.-----	154
XXIV. <i>A</i> , Buttes in sec. 9, T. 148 N., R. 93 W., N. Dak.; <i>B</i> , Buttes in T. 148 N., R. 93 W., N. Dak.-----	160
XXV. <i>A</i> , View up Squaw Creek, N. Dak.; <i>B</i> , Bare buttes in Squaw Creek valley in sec. 10, T. 148 N., R. 93 W., N. Dak.-----	161
XXVI. Sections of lignite beds in the southern part of the Fort Berthold Indian Reservation, N. Dak.-----	172
XXVII. Map of the northern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds-----	In pocket.
XXVIII. Map of the southwestern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds-----	In pocket.
XXIX. Map of the southern part of the Fort Berthold Indian Reservation, N. Dak., showing outcrops of lignite beds-----	In pocket.
FIGURE 13. Index map showing location of Fort Berthold Indian Reservation, N. Dak.-----	110
14. Diagram showing heating value of North Dakota lignite, compared with that of certain subbituminous and bituminous coals-----	123
15. Sections of lignite bed C, Fort Berthold Indian Reservation, N. Dak., showing characteristics of the bed and of partings--	126

LIGNITE IN THE WESTERN PART OF THE FORT BERTHOLD INDIAN RESERVATION SOUTH OF MISSOURI RIVER, NORTH DAKOTA.

By CLYDE MAX. BAUER and FRANK A. HERALD.

INTRODUCTION.

Importance of lignite.—Inasmuch as wood for fuel is practically lacking in the northern Great Plains the lignite of this region is of particular importance in the development of its commerce and industry. The value of lignite in North Dakota is illustrated by its application to the development of agriculture. The early settler and rancher have depended on it either in whole or in part for fuel and power, and the settlement of many districts which are practically destitute of wood has been expedited greatly by its presence. One of these districts which is soon to be opened for settlement is the Fort Berthold Indian Reservation.

Location of field and scope of report.—The Fort Berthold Indian Reservation is in the west-central part of North Dakota, on both sides of Missouri River, about 65 miles northwest of Bismarck, or about halfway between that city and the place where the Missouri enters the State. (See fig. 13.) The reservation lies in the great lignite region of the northern Great Plains and is underlain by many beds of lignite which have been uncovered and measured at a large number of places. The total area of the reservation is about 1,500 square miles, of which approximately 650 square miles in McKenzie, Dunn, and Mercer counties lies south and west of Missouri River and is the subject of this report.

In the following pages the geography and general geology of this part of the reservation are described very briefly, and the lignite beds in detail. The remainder of the reservation has been examined by C. D. Smith,¹ who in 1908 made a reconnaissance of the area adjacent to Missouri River, and by M. A. Pishel,² who in 1910 examined that part of the reservation which lies north and east of the river.

Field work and acknowledgments.—The field work on which the present report is based extended over three seasons. In September

¹ Smith, C. D., The Fort Berthold Indian Reservation lignite field, N. Dak.: U. S. Geol. Survey Bull. 381, pp. 30–39, 1908.

² Pishel, M. A., Lignite in the Fort Berthold Indian Reservation, N. Dak., north of Missouri River: U. S. Geol. Survey Bull. 471, pp. 170–186, 1912.

and October, 1911, a party in charge of F. A. Herald examined the part of the reservation west of Missouri River and north of the south line of T. 149 N. The work was continued during September and October, 1912, by C. M. Bauer, assisted by A. E. Fath and O. H. Pierce. In this year the examination of the part west of Missouri River and north of Little Missouri River was completed. In June and July, 1913, C. M. Bauer, assisted by C. A. Bonine and E. M. Parks, examined that part of the reservation lying south of Little Missouri and Missouri rivers. Acknowledgments are due to M. R. Campbell, for valuable suggestions in preparing the report; to E. G. Woodruff, who had general field supervision in 1911-12;

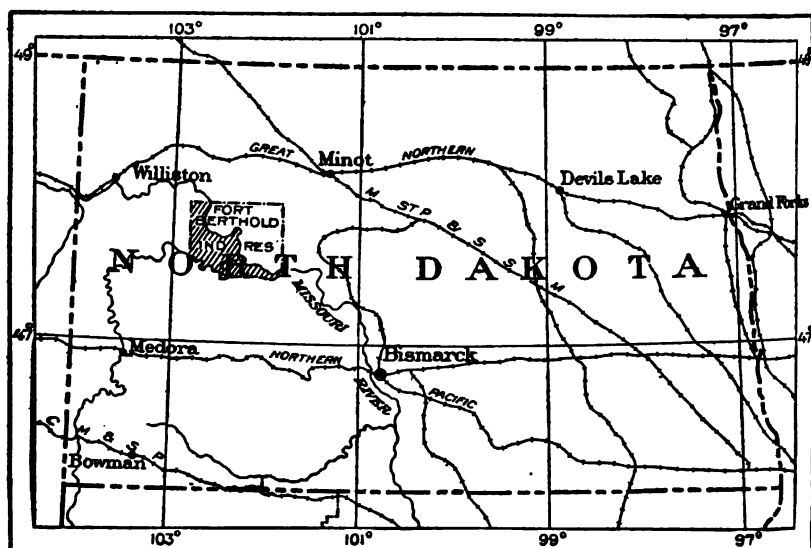


FIGURE 13.—Index map showing location of Fort Berthold Indian Reservation, N. Dak. The area described in this report is indicated by shading.

and to T. W. Stanton and F. H. Knowlton, for the determination of fossil shells and plants collected.

Method of field work.—The examination of the Fort Berthold Reservation was undertaken primarily to obtain data for classifying the land on the basis of its lignite content. All outcrops of lignite beds, especially the places at which measurements of thicknesses were made, were carefully located and mapped on a scale of 2 inches to 1 mile. A telescopic alidade and 15-inch plane table were used, and stadia traverse was employed to make accurate locations. The altitudes of the points located were determined by vertical angles. As the land is classified according to legal subdivisions, all locations were made with respect to land corners. The lignite beds were uncovered in many places by pick and shovel.

and in some places an ordinary wood auger, capable of boring to the depth of 10 feet, was used to prospect for or to determine the thickness of a bed outcropping in a level grass-covered area. Many geologic data were collected incidentally to the examination of lignite beds and are applicable either directly or indirectly to the classification of the land.

Land surveys.—The General Land Office surveys were used as a base upon which to place the economic and geologic data. All the townships west of R. 91 W. were surveyed in 1910, 1911, and 1912. The land corners in these townships are marked by iron pipes with brass tops stamped with the township and section numbers, and in most of the plats the surface features are represented by contour lines with a 50-foot interval. The area from R. 91 W. to the southeast corner of the reservation was surveyed in 1892, and the land corners, being marked by stones, were not readily discovered, although all the corners searched for on the coal outcrops were found.

GEOGRAPHY.

Land forms.—In a broad sense the upland between the streams, as shown in Plate XXII, *B*, is a dissected plain with an average altitude of about 2,100 feet above sea level. On the north and east sides of that part of the Fort Berthold Reservation here described the broad valley of Missouri River, shown in Plate XV, *A*, is eroded to a depth of about 400 feet; on the south the sinuous course of Little Missouri River is intrenched to about the same depth. From the upland the valley of the Little Missouri appears gorgelike, the walls rising precipitously to a height of 300 or 400 feet on either side, but in places they are broken by tributary gullies and valleys, as shown in Plate XIII, *A*. Along the large streams are flood plains ranging in width from a few rods to 1 or 2 miles and commonly separated from the upland by a zone of "breaks," or rough badland country. Surmounting the upland itself are irregular ridges and isolated buttes which rise 300 to 400 feet above the general level.

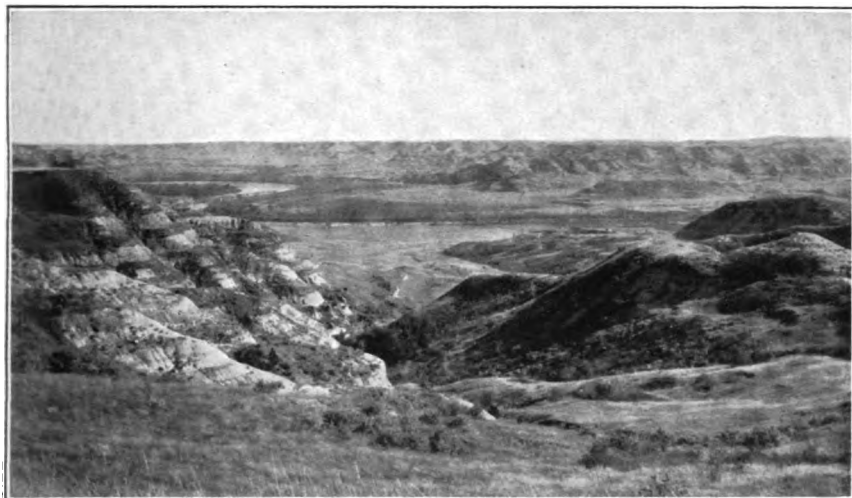
In the northern part of the region (see map, Pl. XXVII, in pocket) the surface is rolling and shows locally the effect of glaciation (see Pl. XIX, *A*). Farther south, on Clark Creek, in T. 151 N., R. 94 W., the rolling plain is broken into badlands, and similar features occur in the valleys of Bear Den and Skunk creeks, which lie still farther to the south, as well as of Moccasin Creek and Little Missouri River (see map). High buttes in T. 151 N., R. 94 W., known as the East Buttes, rise 750 feet above Missouri River. In T. 148 N., Rs. 92 and 93 W., there are other conspicuous ridges and bare buttes, of which Saddle Butte is a striking example. (See Pl. XXVIII.) To the west the plain reaches a greater altitude and the

buttes do not appear to be so high, though their average height above sea level is greater. North of the horse camp, in secs. 9 and 10, T. 148 N., R. 94 W., there is a high grass-covered hill from which a commanding view of most of the western part of the reservation can be obtained, and a little north of this is Eagle's Nest, a comparatively round, bare butte which is a well-known landmark. In the southern part of this township are other prominent buttes which can be seen for many miles. Along Little Missouri River as far east as the mouth of Squaw Creek there are very rough badlands. This badland zone averages about 3 miles in width, but up Moccasin Creek its width is about 6 miles. In the south-central part of T. 147 N., R. 93 W., the maximum relief is more than 600 feet and many of the gullies have nearly vertical sides. (See Pl. XIV, B.)

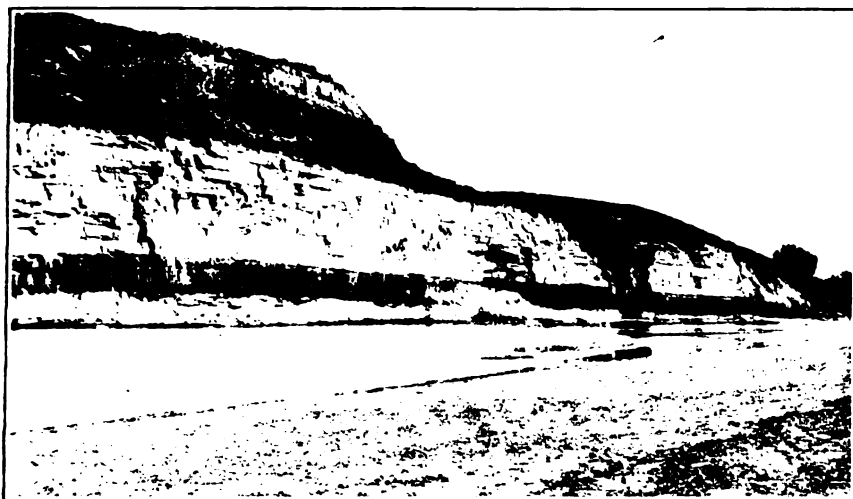
Southeast of Little Missouri River (see map, Pl. XXIX, in pocket) the land rises rather steeply out of badlands to a high rolling plain. This plain contains some excellent grazing and farming land, but in the neighborhood of both Missouri and Little Missouri rivers the land is very much broken by gullies, and badlands are common. Near Crow's Heart Landing, in sec. 1., T. 147 N., R. 91 W., the bluffs are about 400 feet high and break very sharply to the river. In the extreme southeastern part of the reservation the upland is lower, and where the Missouri swings to the north side of its valley the land slopes gently to the river flood plain. A terrace 30 to 40 feet high overlooks the flood plain in the eastern part of T. 147 N., R. 89 W. On Beaver Creek in T. 146 N., R. 88 W., the land is covered with grass and the slopes are gentle.

Drainage.—The southern part of the reservation is drained by Missouri River, in part directly through the main stream and in part through Little Missouri River and numerous smaller tributaries. Missouri River has a sandy channel from a quarter of a mile to a mile in width, the position of which is constantly shifting, giving rise to a wide, barren flat of cross-bedded sand and gravel. The amount of water in the stream is variable, and the channel contains many deeps and shallows which render it dangerous for ferry boats and other craft. The water is always muddy and at times is heavily laden with silt and debris derived largely from the bare, steep slopes of the badlands of the drainage basin. Borings made in the channel of the river 3 miles west of Elbowoods by the Great Northern Railway Co. show the presence of quicksand and river mud to a depth of 60 feet. The alluvium is probably not generally so thick and is commonly spread over a tract roughly coinciding with the river flood plain.

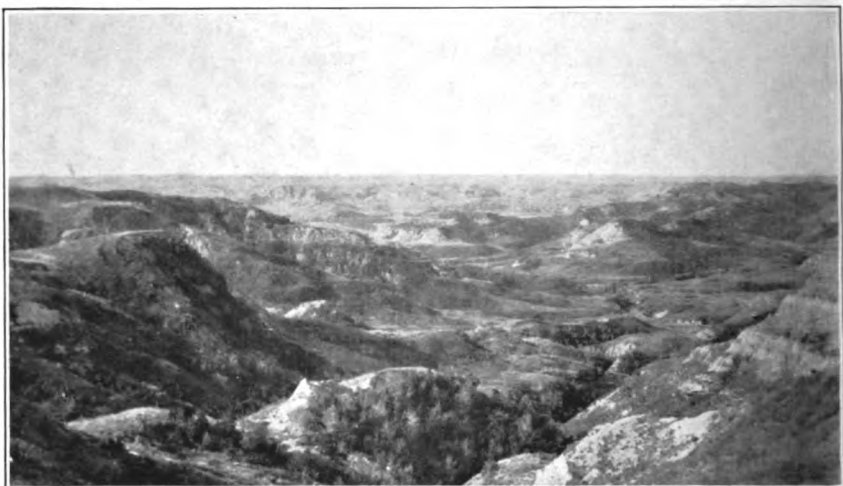
The channel of Little Missouri River is extremely sinuous. The stream meanders in an alluvial flat from half to three-quarters of a mile wide. During most of the year the channel is from 300 to



A. "BREAKS" OF THE LITTLE MISSOURI, LOOKING SOUTHEAST TOWARD THE MOUTH OF HANS CREEK, N. DAK.



B. A THICK BED OF LIGNITE IN THE FORT BERTHOLD INDIAN RESERVATION, N. DAK.



A. BADLANDS IN SEC. 26, T. 147 N., R. 93 W., N. DAK.



B. BADLANDS IN SEC. 25, T. 147 N., R. 93 W., N. DAK.

500 feet wide, but in July and August it carries very little water and can be forded in a few places.

Clark, Bear Den, and Skunk creeks are the chief tributaries of Missouri River in the northern part of the reservation, and Squaw, Moccasin, Sam's, and Hans creeks empty into Little Missouri River in the southern part. Each of these streams has a basin 50 square miles or more in extent and contains flowing water in most of its course throughout the year. Springs and seeps are common on many of the smaller intermittent streams as well as on those just mentioned. Many of the springs issue from the outcrops of lignite beds, because joints in these beds afford free passage for the water that is confined by the relatively impervious adjacent strata. The water is thus conducted down the dip to the outcrop, where it issues in springs.

The spring water in this general region carries a large amount of sodium, calcium, and magnesium sulphate in solution, and around some of the springs there is a deposit of these white alkaline salts. The water in a large number of the springs is discolored by a brownish substance leached from the lignite beds, and the ground in the vicinity of certain springs is covered by thin, scaly layers of this brownish-black material, which is known locally as "black alkali." According to Pishel* it is a hydrocarbon leached from the lignite by the action of alkaline water.

Settlement.—Settlement in the southwestern part of the reservation is confined to the valleys of Missouri and Little Missouri rivers. A large part of the reservation south of the river is unfit for cultivation owing to its badland character, and at present most of it is leased to stockmen and devoted to grazing. Farming is limited to vegetable gardening by a few thrifty Indians, who produce enough for their own use. Experiments in raising vegetables in this region have proved that the soil is generally fertile. Although the annual rainfall is only 17 inches, a large portion of it comes during the growing season and makes successful dry farming possible. At present, however, markets are distant and roads are poor, most of them being merely trails, which in many places follow practically the only passable routes through the rough country. The principal trails are shown on the maps (Pls. XXVII-XXIX, in pocket).

GEOLOGY.

STRATIGRAPHY.

The Fort Berthold lignite field contains rocks of three series, namely the Recent (alluvium) and Pleistocene (glacial drift) series

* Pishel, M. A., Lignite in the Fort Berthold Indian Reservation, N. Dak., north of Missouri River: U. S. Geol. Survey Bull. 471, pp. 177-178, 1912.

of the Quaternary system and the Eocene series (Fort Union formation) of the Tertiary system. Outcrops or exposures of the different formations are more or less widely scattered throughout the field. The glacial drift was not mapped, and the alluvium was mapped only along Missouri and Little Missouri rivers and Hans Creek. The Fort Union formation underlies the entire field and is exposed where the younger formations are absent.

QUATERNARY SYSTEM.

Alluvium.—The alluvium, or recent washed material, is spread out in sheets and ribbon-like deposits on the slopes and along the streams in all parts of the field. It consists of silt, sand, and gravel washed from the older rocks and deposited by the water where the current is checked on account of decreased grade. It ranges in thickness from a few inches to about 60 feet and is thickest in the flood plain of Missouri River. The alluvium is commonly mixed with humus and is sufficiently porous and decomposed to form a basis for good soil. It therefore underlies some of the best agricultural land in the reservation.

Glacial drift.—Both stratified and unstratified drift, probably of Kansan (early Pleistocene) and Wisconsin (late Pleistocene) age, cover large portions of the field and were noted in many localities. In general, however, their thickness is less than 5 feet, and in some places, particularly on the larger streams, they are absent. On Little Missouri River the effects of glaciation can hardly be detected except for the presence, as shown in Plates XIX, A, and XXV, A, of scattered foreign boulders. In the NW. $\frac{1}{4}$ sec. 27, T. 148 N., R. 93 W., and the NE. $\frac{1}{4}$ sec. 23, T. 148 N., R. 92 W., there is some consolidated glacial drift, with a maximum thickness of 15 feet, containing numerous concretions and boulders of shale and sandstone, with a few boulders of granite and limestone. The whole is cemented by gypsum and iron oxide. Along the creek in sec. 7, T. 152 N., R. 93 W., the drift is 37 feet thick but unconsolidated, and at several places in the township to the west it was found to be as thick as 15 feet. This unconsolidated drift is probably younger than Kansan and may belong to the Wisconsin stage of the Pleistocene.

TERTIARY SYSTEM.

FORT UNION FORMATION.

GENERAL CHARACTER.

The lignite-bearing rocks exposed in the Fort Berthold field are a part of the Fort Union formation as described by Meek and Hayden⁴

⁴ Meek, F. B., and Hayden, F. V., Acad. Nat. Sci. Philadelphia Proc., vol. 13, p. 433, 1861.



**A. MISSOURI RIVER, N. DAK., AS SEEN FROM THE UPPER MARGIN OF THE
BADLANDS, LOOKING NORTH.**



**B. VALLEY OF MOCCASIN CREEK NEAR ITS MOUTH, IN SEC. 6, T. 147 N.,
R. 92 W., N. DAK.**

in their Missouri River section and are assigned to the Eocene or early Tertiary. The Fort Union formation has a wide areal distribution, cropping out in parts of Montana, Wyoming, North Dakota, and South Dakota and also extending northward into Canada. Geographically the Fort Berthold field is in the east-central part of this large region. Between the lowest rocks exposed on Missouri River and the highest capping of the buttes there is a thickness of about 850 feet of strata. The exact stratigraphic position of that part of the Fort Union which is exposed in the Fort Berthold field is not known, but on the assumption that the original thickness is comparable to the known thickness in Billings County, N. Dak.,^{*} it seems probable that there is about 200 feet of the formation underlying the lowest exposed stratum in the reservation.

The formation consists of shale, clay, sandstone, and beds of lignite which range in thickness from a few inches to 15 or 20 feet. The strata are dull gray in general appearance, with bands of lighter colors, some of which may be traced for several miles. These bands, however, are not confined to definite strata. A light-colored band may follow one stratum continuously for several miles and then gradually rise or fall in the stratigraphic section. Locally sandy shale grades almost imperceptibly into clayey sandstone within short distances. Certain comparatively thin lenticular layers of limestone are deserving of especial mention. They are bluish gray when fresh but usually weather into light-buff angular fragments. These lenses are generally fossiliferous, containing both leaves and shells.

A siliceous bed, apparently containing no lime, was traced across T. 148 N., Rs. 92 and 93 W. Its average thickness is not more than 18 inches. In fresh exposures it is dark and friable, but where weathered it is white and very resistant, and residual fragments are strewn upon low buttes and scattered widely in front of the outcrop. Many of the weathered boulders show numerous impressions of plant stems and roots. The abundance of plant remains, particularly the casts of stems and roots, in this quartzite suggests that it originated from a soil or muck deposit and that subsequently silica-bearing waters replaced most of the carbon. A microscopic examination shows the rock to be composed almost entirely of minute angular grains of quartz with scattered particles of black material resembling carbon.

Cross-bedding of shale and sandy shale as well as sandstone is very common in the Fort Union formation. This feature is particularly well shown in a lens of reddish-brown sandy shale which crops out in T. 147 N., R. 92 W., and ranges in thickness from about 1 foot to 18 feet within a horizontal distance of less than a mile. In some

^{*} Lloyd, E. R., and Hares, C. J., The Cannonball marine member of the Lance formation: *Jour. Geology*, vol. 23, pp. 528-547, 1915.

places the material of this bed crumbles in the hand and is very sandy; in other places it contains laminae of soft flaky shale which carries plant remains and carbonaceous material to such an extent that its color is chocolate-brown.

Some of the sandstones of this formation weather into peculiar loglike forms, examples of which are shown in Plate XVIII, *B*. It is supposed that these forms are really concretions, but some geologists have maintained that this particular phase of weathering is due to some irregularity in deposition, possibly in the form of sand bars or sand spits.

FOSSILS.

The early Tertiary or Fort Union age of the coal-bearing formation in the Fort Berthold Indian Reservation is established not only by its continuity with the type Fort Union formation at the mouth of Yellowstone River, but by fossil plants and shells which were collected at several horizons in the formation in this field. A list of these fossils obtained from the southeastern part of the reservation is given below:

Fossil plants.

6683. NE. $\frac{1}{4}$ sec. 13, T. 147 N., R. 91 W.:

Viburnum nordenskiöldi? Heer.

Populus sp.

6693. NE. $\frac{1}{4}$ sec. 36, T. 147 N., R. 89 W.:

Sequoia nordenskiöldi Heer.

Celastrus sp.

Celastrus ovatus Ward.

6694. NW. $\frac{1}{4}$ sec. 35, T. 147 N., R. 89 W.:

Glyptostrobus europaeus Unger.

Dicotyledonous fragments.

6693. SE. $\frac{1}{4}$ sec. 10, T. 147 N., R. 91 W.:

Platanus nobilis Newberry.

Fragments.

Fossil shells.

8557. SE. $\frac{1}{4}$ sec. 7, T. 147 N., R. 91 W., in clay above bed FF:

Unio sp.

Viviparus.

8558. SE. $\frac{1}{4}$ sec. 5, T. 147 N., R. 91 W., 10 feet above bed GG:

Unio sp.

Goniobasis nebrascensis Meek and Hayden.

Owing to the ease with which the fossil-bearing rocks crumble it is difficult to preserve the specimens collected, and many of the fossils obtained are broken to fragments in transit before they can be examined and identified. For that reason the number of determinable species obtained from this field is small. Those listed above are referred by Messrs. Knowlton and Stanton to the Fort Union.

CLINKER.

Red baked rock, known locally as "scoria" or clinker, is common at certain horizons in the Fort Union formation. In several localities, particularly in secs. 21 and 28, T. 148 N., R. 93 W., and secs. 16, 17, 20, and 21, T. 147 N., R. 93 W., it covers areas a square mile or more in extent. The clinker is formed by the burning of beds of lignite on their outcrop. The ignition of the lignite may have been due to prairie fire, lightning, the agency of man, spontaneous combustion caused by rapid oxidation on weathering, or other causes.

The burning becomes slower as it progresses back from the outcrop under thickening cover, owing to a decrease in the supply of air. The lignite in the vicinity of the fire may be heated to the kindling temperature, but owing to lack of air it smolders until slumping takes place, admitting air or directly exposing fresh surfaces of heated lignite, which then begin to burn. Sometimes crevices afford natural chimneys, and in these openings the heat becomes intense. In such places the overlying clay and shale have been fused by the heat and the product is vesicular and shows flow structure. Many beautiful colors are developed, differing according to the composition of the rocks and the temperature to which they have been subjected.

If a bed of lignite is under thick cover when it is burning, the thickness of the clinker produced at or near the outcrop generally varies directly as the thickness of the lignite, though thick beds of lignite may burn slowly without fusing the adjacent strata. On the other hand, if the cover is thin it may be affected throughout, even by the burning of thin beds, and combustion may continue under large areas. As the quantity of ash which remains is smaller than the quantity of lignite burned the total thickness of the strata is materially diminished in areas of considerable burning, and the overlying beds settle. This causes local discordance in the dip of the beds above and below zones of burning.

In mapping the outcrops of lignite beds in this field the burned areas were located, and their extent is shown on the maps (Pls. XXVII-XXIX, in pocket). In most localities the extent of the burning could be mapped with a fair degree of certainty; but in a few places where the cover is thin the effect of the fire is uncertain, hence the approximate edge of the lignite bed in these places is represented by a broken line.

STRUCTURE.

Except for slight undulations, which in some places show noticeable dips for short distances, the beds of the Fort Union formation lie nearly flat. These local variations in direction and degree of dip

are numerous, but as the dips are commonly less than 2° they are not easily detected. By comparing the carefully determined altitudes of many points on the outcrops of the lignite beds it was found that the strata in the western part of the area dip in general in a northeasterly direction at an average rate of less than 8 feet to the mile. The lowest point structurally in the area is in the southeastern part of T. 149 N., R. 91 W., and east of this point the strata rises toward the east at the rate of a few feet to the mile. Observations on the minor undulations are given in the township descriptions (pp. 129-172).

ORIGIN OF THE COAL-BEARING FORMATION.

A full discussion of the problem of the origin of the Fort Union formation will not be presented here, but only a preliminary statement of the meaning of some of the prominent features as suggested in the cursory study of this field.

It is probable that the generally tilted attitude of the strata in this part of North Dakota is due partly to deformation and partly to the original slope of deposition. To what degree deformation has affected the strata since they were laid down is difficult to determine, but it seems certain that many of the minor undulations noted in the outcropping portion of the formation are due largely to the varying thickness of the strata themselves as well as of the underlying beds. Not only do its fossil remains of plants and animals indicate that the Fort Union formation was made up largely of sediments deposited in fresh water, but the character and constitution of the beds themselves furnish additional evidence of their continental origin. Some of the beds show ripple marks, shrinkage cracks, and silicified tree stumps (Pl. XXI, *B*) in place, indicating that they originated in very shallow water and that possibly part of their material is wind blown. Other beds indicate deeper and more quiet water, but the tree trunks, limbs, and knots (Pl. XXI, *A*) which are so well preserved in the lignite beds show clearly that forests must have existed in the area where a considerable part of the lignite was deposited. As a result of the deposition of the sediments in lakes and swamps and on flood plains, many of the beds, both of sandstone and shale, are lenticular and cross-bedded, like shale that originates in extensive deltas. At times during the deposition of the strata large areas of the sediments were covered by shallow, stagnant water in which vegetation grew and carbonaceous material accumulated. Owing to occasional changes in climate, or to further submergence of the sediments, these swamps were at times replaced by deeper water. The stronger currents consequent on these changes brought about conditions favorable to the deposition of sand and mud, which when indurated formed sandstone and

shale. The weight of these later sediments helped to compress the carbonaceous material into lignite.

Since their deposition the strata have been elevated and subjected to long periods of erosion. Streams have removed hundreds of feet of material and are still furrowing the strata and carrying the debris seaward. Glaciers have also covered the region and in places have reduced the relief by rounding off the hills and partly filling the valleys.

LIGNITE.

PHYSICAL PROPERTIES.

The most pronounced physical property of lignite is its tendency to slack on exposure to the air. This tendency is due to the fact that it contains a large percentage of water, which evaporates on exposure, causing shrinkage and the development of an irregular network of cracks and an eventual breaking up into small irregular fragments. Fresh lignite is dark brown and has a dull to waxy luster. In the bed the principal structure is usually parallel to the bedding, in places laminated, and generally shows a cubic jointing. The texture is dense in some places and woody in others. The wood is in many places so well preserved that it still retains its elasticity and may be bent in the hands to a considerable angle and will spring back to its original position. Pieces of wood and stems are generally flattened, such harder parts as knots being best preserved. The lignite contains other minerals in small quantities; the commonest are gypsum and iron pyrites. Some layers contain a large percentage of mineral charcoal, which may indicate extensive fires or temporary desiccation of the swamps^a during the accumulation of the vegetable matter.

CHEMICAL CHARACTER.

In the examination of the western part of the Fort Berthold Reservation it was not possible without a great amount of labor to obtain samples of lignite sufficiently fresh to give valuable results on chemical analysis. The chemical composition of North Dakota lignite, however, is well known from the results of numerous analyses of samples collected in many parts of the State, either from working mines or from freshly opened prospects. Six representative analyses of lignite from neighboring fields have been selected and may be accepted as showing fairly accurately the composition of the lignite in this reservation. Five analyses of bituminous coal are also given in the accompanying table for comparison of values.

^a Savage, T. E., On the conditions under which the vegetable matter of the Illinois coal beds accumulated: Jour. Geology, vol. 22, pp. 754-765, 1914. White, David, and Thlessen, R., The origin of coal: Bur. Mines Bull. 38, 1913.

In the table the analyses are given in four forms, marked A, B, C, D. Form 'A' is the analysis of the lignite exactly as it comes from the mine. Owing to the fact, however, that the original moisture content of a sample is largely a matter of accident and depends in part on the amount of water in the mine from which it came, it is best for comparative purposes to use form B, which is the analysis of the sample air-dried under uniform conditions. Form C is the theoretical analysis of the sample after all moisture has been eliminated. Form D is also computed and is the analysis of the sample after all moisture and ash have been theoretically removed. Neither of the two conditions last mentioned exists in nature, but form C is used by mechanical engineers and form D is valuable for comparing the quality of the pure coal substance and the effect on its heating value of the impurities present. The analyses given show a moisture content in the samples as received ranging from 34.8 to 44.1 per cent and in the air-dried samples from 8.6 to 12.6 per cent. The heat value of the air-dried samples ranges from 8,600 to 9,860 British thermal units.

Analyses of coal and lignite samples from North Dakota fields and from fields sending coal into the Fort Berthold district.
 [Made at the Pittsburgh laboratory of the Bureau of Mines; F. M. Stanton and A. C. Fieldner, chemists.]

	Location.			Designation on fig. 14.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value.	
	Quar-ter.	Sec.	T.					Mol-ec-u-lar.	Volatile matter.	Fixed carbon.	Ash.	Sul-phur.	Hydro-gen.	Carbon.	Nitro-gen.	Oxy-gen.	Calo-ries.	British thermal units.
Washburne Lignite Coal Co., Wilton, N. Dak.	.....	1	142 N.	80 W.	D.....	1935	32.3	A	40.5	37.1	37.4	5.0	76	.....	.....	.....	3,690	6,640
								B	12.1	38.9	40.4	7.5	1.12	.....	.....	.....	6,450	9,810
								C	.....	45.5	46.0	8.5	1.28	.....	.....	.....	6,205	11,170
								D	.....	46.7	50.3	1.40	.....	.....	.....	.....	6,755	11,210
Consolidated Coal Co., Lehigh, N. Dak.	.....	8	139 N.	95 W.	C.....	1971	35.6	A	42.1	34.5	25.7	7.7	1.13	.....	.....	.....	3,420	6,160
								B	10.0	38.1	40.0	11.9	1.75	.....	.....	.....	5,310	9,560
								C	.....	43.4	44.4	13.2	1.95	.....	.....	.....	5,905	10,630
								D	.....	45.8	51.2	2.25	.....	.....	.....	.....	6,805	12,250
Dakota Products Mine Co., New Salem, N. Dak.	.....	15	139 N.	85 W.	E.....	20033	32.7	A	38.5	27.6	28.6	7.28	1.31	7.03	38.22	44.56	3,725	6,700
								B	8.6	41.1	39.5	10.83	1.95	5.04	85.31	22.98	5,335	9,970
								C	.....	44.9	43.3	11.84	2.13	4.47	68.79	16.79	6,055	10,900
								D	.....	50.9	49.1	.....	2.42	5.07	72.36	1.11	6,870	12,360
U. S. Reclamation Service, Williston, N. Dak.	.....	7	154 N.	100 W.	B.....	19357	32.8	A	44.1	22.8	28.3	5.76	.56	7.28	38.11	46.66	3,355	6,040
								B	16.9	35.4	34.1	8.35	.84	5.40	63.74	.94	4,960	8,960
								C	.....	42.6	47.1	10.32	1.00	4.25	64.05	1.13	6,005	10,810
								D	.....	47.5	52.5	.....	1.12	4.74	72.11	1.26	6,565	12,060
Beulah mine, Beulah, N. Dak.	.....	25	144 N.	88 W.	F.....	33069	28.9	A	34.8	28.2	30.8	6.20	.70	6.73	42.41	43.27	4,005	7,210
								B	10.9	35.3	42.1	8.45	.96	5.12	65.00	1.94	5,560	9,860
								C	.....	47.3	52.3	9.51	1.67	4.39	65.07	1.76	6,465	11,080
								D	.....	47.8	52.2	.....	1.18	4.86	71.91	1.17	6,780	12,230
Cannon mine of J. F. Casteel, Burlington, N. Dak.	.....	.....	150 N.	84 W.	A.....	31705	30.1	A	37.0	24.9	27.7	10.43	.23	6.39	37.36	61	3,340	6,010
								B	4.8	35.6	34.7	14.82	.32	4.38	53.43	87	5,775	8,990
								C	.....	39.5	44.0	15.54	.35	3.63	59.23	97	5,295	8,530
								D	.....	47.3	52.7	.....	.49	4.33	70.97	1.16	6,345	11,430
Monarch mine, Sheridan, Wyo	SE.....	24	57 N.	85 W.	G.....	12005	11.1	A	22.8	35.0	38.0	3.73	.37	6.27	55.28	33.28	5,245	9,620
								B	12.5	39.4	43.9	4.20	.49	5.67	62.18	1.20	6,010	10,920
								C	.....	45.0	50.2	4.60	.56	4.89	71.10	1.38	6,870	12,370
								D	.....	47.3	52.7	.....	.49	5.14	74.68	1.45	7,230	12,990
Cottonwood Coal Co., Sand Coulee, Mont.	NW	36	19 N.	4 E.	H.....	4115	2.4	A	6.0	28.5	51.4	14.14	2.38	4.46	63.61	.91	6,195	11,150
								B	3.7	29.1	52.7	14.40	2.44	4.28	65.13	.93	6,350	11,430
								C	.....	30.3	54.7	15.04	2.53	4.03	67.67	.97	6,590	11,870
								D	.....	35.6	64.4	.....	2.68	4.75	70.66	1.14	7,760	13,970

Analyses of coal and lignite samples from North Dakota fields and from fields sending coal into the Fort Berthold district—Continued.

	Location.			Designation on fig. 14.	Laboratory No.	Air-drying loss.	Form of analysis.	Proximate.				Ultimate.					Heating value.	
	Quar. Sec.	T.	R.					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific.	British thermal units.
Galt mine, Canadian Pacific Ry., Lethbridge, Canada.		9 N...	22 E...	I.....	14882	2.0	A	9.8	40.1	43.3	6.77	.71	5.90	64.99	1.73	20.20	6,340	11,410
							B	7.9	41.0	44.2	6.91	.72	5.49	66.32	1.77	18.76	6,470	11,640
							C	.....	44.5	48.0	7.50	.79	5.90	72.04	1.93	12.75	7,030	12,650
							D	.....	48.1	51.9	.....	.85	5.41	77.88	2.08	13.78	7,000	13,680
Coal No. 6, Hocking Valley, Ohio.				J.....	7712	5.5	A	9.8	32.4	53.4	4.43	.54	5.70	69.50	1.26	18.58	6,805	12,250
							B	4.5	34.3	56.5	4.69	.57	5.38	73.55	1.32	14.49	7,200	12,980
							C	.....	35.9	59.2	4.91	.60	5.12	76.99	1.38	11.00	7,535	13,570
							D	.....	37.8	62.2	.....	.63	5.38	80.96	1.45	11.58	7,925	14,270
Pittsburgh coal, Fayette County, Pa.				K.....	23097	1.2	A	2.5	35.7	53.6	8.17	1.76	5.19	76.16	1.49	7.24	7,685	13,650
							B	1.3	36.1	54.3	8.27	1.78	5.12	77.08	1.51	6.24	7,675	13,800
							C	.....	36.6	55.0	8.38	1.81	5.04	78.13	1.53	5.11	7,780	14,000
							D	.....	40.0	60.0	.....	1.98	5.50	85.28	1.67	5.57	8,490	15,290

Most users of lignite are little concerned about the percentage of sulphur it contains or even the relative amounts of volatile matter and fixed carbon, but they are vitally interested in the heat-producing quality of the lignite, for this determines its value for ordinary purposes, such as heating buildings, raising steam, and manufacturing uses generally.

Many persons think it best to foster home industries, even though it involves some sacrifice on their part, but to most persons the deciding question regarding a fuel as well as any other commodity is that of economy, and economy in the purchase of fuel means generally the getting of fuel with the greatest heating power for the least money. Lignite is so different from bituminous coal that most persons are unable to make a direct comparison, but such a comparison

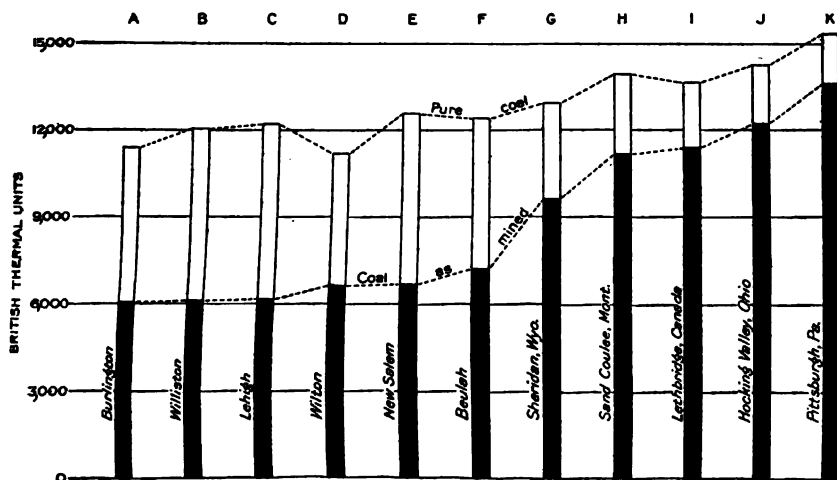


FIGURE 14.—Diagram showing heating value of North Dakota lignite compared with that of certain subbituminous and bituminous coals. See text for explanation.

is essential in order to determine which kind of fuel is the most economical to use. The ordinary analysis of a coal will not furnish the data directly for the comparison, but the calorific determinations given in the table on pages 121-122 will enable anyone to make a direct comparison of the coals and lignites there listed, and in fact their comparative values may be expressed in dollars and cents.

Figure 14 shows graphically the heating value of certain of the coals and lignites whose analyses are given on pages 121-122. These analyses have been selected because they were made from samples collected in working mines and so had suffered no deterioration from exposure to the weather. For convenience in reference these analyses will be designated A, B, C, etc., as shown in the diagram. A to F represent samples from neighboring fields of North

Dakota, in which the lignite is essentially of the same heating value as that of the Fort Berthold Reservation. G is one of the standard subbituminous coals of Wyoming, and I a similar though better coal from Lethbridge, Canada. H is a bituminous coal from Sand Coulee, near Great Falls, Mont., and J and K are two well-known eastern bituminous coals—the Hocking Valley coal of Ohio and the Pittsburgh coal of Pennsylvania. If mines are developed in the Fort Berthold Reservation the output will be likely to come into active competition with one or more of the coals represented in figure 14, and for that reason their relative values should be known alike to the producer and to the consumer.

The line marked “pure coal” shows the comparative heating value of the coals in nearly the pure form—that is, after the moisture and ash, the ordinary impurities, have been eliminated. This line, so far as it concerns the lignite, is nearly horizontal, showing that, in their pure form, the lignites differ but little in their heating value. According to this line the lignites here considered rank as follows: E, F, C, B, A, D. In other words, the New Salem lignite is intrinsically a little better than any other lignite here considered. The line marked “pure coal” ascends rapidly to the right, reaching its highest point at K. This shows that the best coal represented in the table is the Pittsburgh coal, and that both this and the Hocking Valley coal are superior in heating value to the coals of Wyoming and Montana here considered.

The comparison just made is interesting, but it has no practical value because it refers to pure coal and not to coal in the bin. The line marked “coal as mined” shows the comparative heating values of the coals as they are taken from the mine, which is in approximately the same condition as when they are consumed. This line shows much greater variations than the line marked “pure coal,” because it involves not only inherent differences in the coal substance but also differences due to the presence of ash and moisture, both of which are very detrimental to a fuel. The lignites stand in the following order: F, E, D, C, B, A. The Beulah lignite is a little the best, New Salem a close second, and Wilton third. Here again the subbituminous and bituminous coals stand higher than the lignites. The difference between them is more marked than it is in the other line, mainly because the high-rank coals contain little moisture, whereas lignite is heavily charged with it.

The relative values to the consumer are proportional to the British thermal units in the coal “as received.” For example, the values of Burlington lignite and Pittsburgh coal are as 6,010 is to 13,650; or, expressed in another way, if Burlington lignite sells for \$5 a ton the consumer could afford to pay \$11.36 for Pittsburgh coal. If he could buy Pittsburgh coal for less than that amount it would be

cheaper than the lignite, but if it cost more than that the lignite would be the cheaper of the two.

The comparative values of the lignites and coals shown in the diagram, on the assumption that Burlington lignite costs \$5 a ton, are as follows:

Burlington lignite.....	\$5.00
Williston lignite.....	5.02
Lehigh lignite.....	5.12
Wilton lignite.....	5.52
New Salem lignite.....	5.57
Beulah lignite.....	6.00
Sheridan subbituminous coal.....	8.00
Sand Coulee bituminous coal.....	9.28
Lethbridge subbituminous coal.....	9.49
Hocking Valley bituminous coal.....	10.19
Pittsburgh bituminous coal.....	11.36

QUANTITY.

An estimate of the quantity of lignite within a given field presents many difficulties, even if data on the outcrops of the beds are abundant. Lignite beds are not only lenticular in cross section, but their areal distribution is extremely irregular. In the following estimate only beds 2 feet or more in thickness are considered. For a bed that is more than 2 feet thick in one locality and less in another, the extent of the thick portion was carefully estimated and the thin portion was ignored. Another factor to be taken into account in estimating the tonnage for this field is the amount of each bed which has been carried away by the erosive action of streams. It is calculated from topographic data that 30 to 40 per cent of the exposed portion of the lignite-bearing formation has been removed in this way. In estimating the amount of lignite in the several beds it was necessary to assume that each bed maintained under cover characteristics similar to those which were discovered on the outcrop. For beds high in the section a large amount of data per unit of area could be obtained, because of the excellent exposures along their sinuous outcrops, but for low beds the data are more meager. Bed A, which is the lowest one outcropping in the field, has on its outcrop an average thickness of 8 feet and is assumed to maintain that average in the area north of the twelfth standard parallel. South of that parallel there are no outcrops of bed A, but it is assumed to underlie the southern part of the field, with an average thickness of 6 feet. The area of this bed used in the computation therefore nearly coincides with the area of the field. In obtaining the quantity of lignite in beds higher than bed A, the area in acres and the average thickness in feet of each bed was obtained. The product of these multiplied by 1,800, which is the

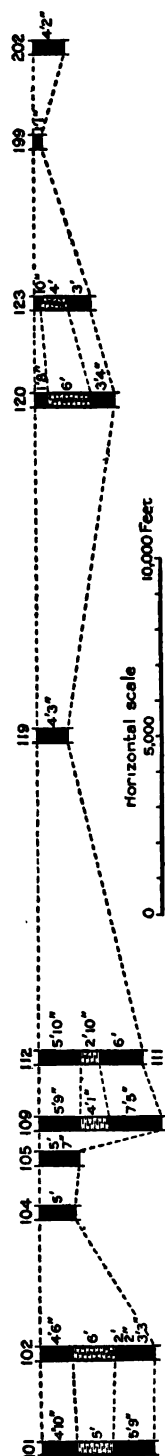


FIGURE 15.—Sections of lignite bed C, Fort Berthold Indian Reservation, N. Dak., showing characteristics of the bed and of its partings.

approximate weight in short tons of a bed of lignite 1 acre in extent and 1 foot thick, gave the tonnage for each bed. The total quantity of lignite estimated in this way is 8,655,000,000 short tons.

If this amount were distributed equally throughout the field and concentrated into one stratum, it would form one bed $11\frac{1}{2}$ feet thick. As a matter of fact, however, the lignite is localized, as noted in the township descriptions, both by its lenticular habit and by erosion, so that large areas contain much less than $11\frac{1}{2}$ feet of lignite in beds 2 feet or more in thickness, whereas other areas may contain as much as 25 feet or more. In addition to the estimated quantity, there is a large tonnage in beds less than 2 feet thick, which is not of value at present and is very difficult to estimate.

DISTRIBUTION.

Beds of lignite are well exposed in the bluffs of Missouri and Little Missouri rivers (see Pls. XIII, *B* and XIX, *B*) and on most of the tributary creeks as far as the badlands extend. Outcrops of some of these beds are continuous for distances ranging from 5 to 30 miles or even more. Other beds are lenticular and within short distances range from a few inches to several feet in thickness. A conspicuous example of this extensive variation in thickness is furnished by bed C in T. 151 N., R. 94 W., as shown in figure 15. The several stratigraphic sections from different parts of the field, given on Plate XVI, also show the variation of the beds from place to place.

It follows from the preceding statements that the total amount of lignite in any stratigraphic section varies within wide limits, but nowhere in this field is there exposed as much as 500 feet of the Fort Union formation which does not contain one or more beds of lignite 2 feet or more in thickness. It is therefore probable that the entire area is underlain by lignite beds, some of which do not crop out in the field but are nevertheless near enough to the surface to be of value.

At least 14 beds of lignite in this field have been considered valuable enough to map—that is, they contain 2 feet or more of lignite somewhere along their outcrops. The correlation of the outcrops is in many places difficult, owing to the variation in the thickness of the lignite beds as well as in the thickness and composition of the strata between them. Some beds, however, that show exceptional thickness or uncommon partings or other striking characteristics can be used as keys for correlation, providing the distance between the outcrops is not too great. Correlation between some beds of lignite that crop out on opposite sides of Missouri River is therefore possible and can be made with considerable certainty. A bed of lignite called bed C in this report is correlated with bed 1 described by Pishel,⁷ and likewise bed CC of this report is probably the same as bed 1-A north of the river. Further correlations of beds on opposite sides of Missouri River will not be attempted owing to the great variations in the stratigraphic sections within short distances and the difficulty of drawing exact conclusions without first-hand knowledge of the stratigraphy on both sides of the river.

DEVELOPMENT.

At present the lignite in the western part of the Fort Berthold Indian Reservation is used very little. The region is almost unsettled, and only a few log houses, occupied by Indians, are built in the valleys of Missouri and Little Missouri rivers. The upland is inhabited by a few transient stockmen, who lease the land for grazing. Wood can be obtained along the principal streams, and lignite is used in conjunction with wood only during the winter. Hence the lignite has not been mined to any extent, and that which is used is obtained directly from outcrops. As lignite is plentiful in the surrounding country, no attempt has been made to market the fuel in settlements bordering the reservation.

Roads are poor and in many places are mere trails; therefore hauling for long distances is expensive, and railroads have not entered the reservation west of Missouri River. The nearest railway station is Sanish, on the left bank of the Missouri near the north line of the reservation. The most accessible railway from the southern part of the region is a branch of the Northern Pacific that ends at Killdeer, about 16 miles south of the southwest corner of the reservation, and extends eastward nearly parallel with its south boundary. The lack of transportation facilities, together with the poor shipping qualities of the lignite, preclude extensive exploitation of it in this field for many years. As general commercial de-

⁷ Pishel, M. A., *Lignite in the Fort Berthold Indian Reservation, N. Dak., north of Missouri River*: U. S. Geol. Survey Bull. 471, pp. 170-186, 1912.

velopment in this region proceeds, however, the lignite will probably be used in near-by power plants or made into briquets for shipping, as lignite briquets have proved a very satisfactory and good stocking fuel.⁸ But when the location of the field and the added cost of briquetting are considered, it seems improbable that the lignite of the Fort Berthold field will be able to compete in outside markets until the supply of high-grade coal is sufficiently diminished to render lignite briquets economical for general industrial use.

LIGNITE BEDS.

The positions in the stratigraphic section occupied by the lignite beds are shown in Plate XVI. The lowest bed of lignite exposed crops out along the foot of the river bluff in T. 151 N., R. 94 W., and as far south as sec. 18, T. 150 N., R. 93 W. It also crops out in many cut banks in the bottom of the valley of Bear Den Creek. As it is the lowest bed of lignite exposed in this field it is called bed A for convenience. From numerous measurements on bed A it was found to average nearly 8 feet in thickness. Owing to a local easterly dip of about 75 feet to the mile in the eastern part of T. 151 N., R. 94 W., and also in T. 151 N., R. 93 W., this bed does not crop out in the reservation east of Missouri River, but it probably underlies large areas on both sides of the river.

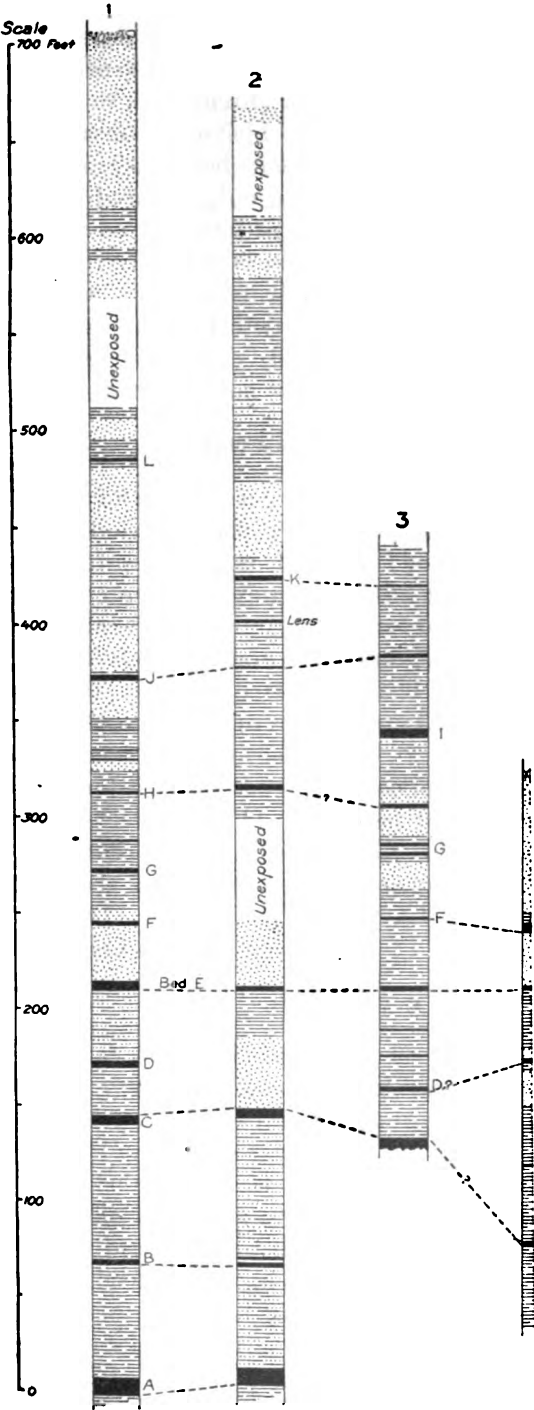
Bed B, the next higher bed of lignite of any value, is lenticular, and its valuable portion lies largely in Tps. 150 and 151 N., R. 94 W. Its outcrop along Clark and Bear Den creeks shows it to be variable in thickness and quality, carrying in many places much impure lignite and carbonaceous shale.

Beds C and CC, which may be the same, are remarkably widespread, cropping out in a large number of places from the northernmost township to the extreme southeasternmost part of the field. Their average thickness is nearly 4 feet, but in many places they are much thicker.

Beds D and DD are similar in character. They occur at about the same stratigraphic position and are variable in quality and thickness. Bed D is valuable in Tps. 150 and 151 N., R. 94 W., and bed DD, which occupies only a small area, reaches its maximum thickness of 5½ feet at location 851, in T. 146 N., R. 88 W.

Another valuable bed of lignite of wide extent in this field is bed E, which is probably the same as bed EE. This bed has been mapped almost continuously from sec. 36, T. 152 N., R. 95 W., to the southeastern extremity of the reservation in T. 146 N., R. 88 W. It averages about 4 feet in thickness, but near the western boundary of

⁸ Babcock, E. J., Investigation of lignite coal relative to the production of gas and briquets: North Dakota Univ. Rept. School of Mines and Exper. Sta., 1911.



STRATIGRAPHIC SECTIONS IN FORT BERTHOLI
CORRELATION ()

Numbers expla

the reservation it reaches a thickness of 14 feet 9 inches, and near Crow's Heart Landing it thins to less than 2 feet. In general, however, it is of such quality and thickness as to make it one of the most valuable beds in the field. In places this bed contains a small parting of shale and silicified wood, which aids in its recognition.

Beds of lignite higher in the section do not underlie as large areas as the lower beds, owing to the fact that large portions of them have been removed by the erosive action of the rivers and their numerous tributaries. Because of this erosion many of the higher beds appear to have only a local distribution, whereas originally they may have been coextensive with those beneath. Each of these beds will be described in connection with the township in which it crops out.

TOWNSHIP DESCRIPTIONS.

A description of each township in the region examined, setting forth the main surface features, with a detailed statement of its lignite resources, is given below. The descriptions are presented in geographic order, beginning at the north line of the field (see Pl. XXVII) and proceeding from east to west along each tier of townships until the area shown in Plate XXVIII is reached. The townships of the southern part of the field (represented in Pl. XXIX) are described from north to south along each succeeding range beginning with the northwest corner.

The numbering of the lignite sections is consecutive from north to south on Plate XXVII, from east to west on Plate XXVIII, and from west to east on Plate XXIX. Many of the measurements of lignite beds 2 feet or more in thickness are shown graphically on Plates XVII, XX, XXIII, and XXVI, with numbers corresponding to those used on the maps.

T. 152 N., R. 93 W.

Only that part of T. 152 N., R. 93 W., that lies within the reservation and west of Missouri River was examined by the Geological Survey party. (See Pl. XXVII, in pocket.) The surface is a rolling upland on the west, bordered on the east by a rather abrupt but low bluff, below and east of which lies the flat flood plain of Missouri River. The upland is grass grown; the flood plain is covered with trees and brush. The lignite-bearing strata are largely concealed beneath glacial drift and alluvium, so that exposures of them are almost lacking in that part of the township which lies west of the river. On a creek in the SW. $\frac{1}{4}$ sec. 7 the drift reaches a thickness of 37 feet. The measurements of lignite beds at locations 1, 2, and 3, in sec. 15, and 7, in sec. 20, are shown diagrammatically in the accompanying plate of lignite sections (Pl. XVII), but owing to insufficient

exposures the beds measured at these places could not be correlated either with one another or with beds in adjoining townships. At location 4 the following section is exposed:

Section of lignite bed at location 4, sec. 16, T. 152 N., R. 93 W.

Shale.	Ft.	in.
Lignite -----		6
Shale -----	21	
Sandstone -----	4	
Lignite -----		11
Shale.		
	26	5

At location 5, in sec. 16, two thin beds of lignite, the upper of which is 9 inches thick and the lower 6 inches, are separated by 3 feet of shale. At location 6, on the same bed as location 7, in sec. 20 (Pl. XVII), 1 foot 8 inches of lignite is exposed, which, however, is not the full thickness of the bed, as the upper portion has been eroded and the remainder is now covered by glacial drift. No attempt was made to correlate these beds of lignite, as the exposures are far apart and of small extent.

A bed of lignite (called bed C in this report), which is over 5 feet thick at locations 8 and 9 (see Pl. XVII), in sec. 36 of the township immediately to the west, probably underlies the southwestern portion of this township also. The approximate outcrop of this bed in secs. 30 and 31 is shown on Plate XXVII (in pocket).

T. 152 N., R. 94 W.

Only that part of T. 152 N., R. 94 W., which lies within the reservation was examined by the Geological Survey party. The surface is rolling and grass covered. The greatest difference in elevation between any two points in the township is about 300 feet. In general the surface material is glacial drift, and outcrops of stratified rocks are few and of small extent; the principal exposures occur in secs. 11, 12, 20, 31, 32, and 36. No lignite beds of commercial importance crop out in secs. 11 and 12. At location 10, sec. 20, however, 10 inches of lignite is exposed, and at location 11 the following section was measured:

Section of lignite bed at location 11, sec. 20, T. 152 N., R. 94 W.

Shale.	Ft.	in.
Lignite -----		5
Shale -----		2
Lignite (bottom of bed not exposed) -----	1	10+
	2	5+

The beds of lignite represented by these sections are high in the stratigraphic section of this field and are not correlated with any other beds. At location 11 a local dip of 7° NE. was noted, but it is probable that this dip does not persist for more than a few hundred feet. Representative sections of beds of lignite are very difficult to obtain, owing to the covering of glacial drift and the disturbed condition of the strata, caused by the movement of the ice sheet. It is probable, however, that bed C, measured at locations 8 and 9, in sec. 36, underlies the greater part of this township at a depth of less than 300 feet. The bed averages $5\frac{1}{2}$ feet in thickness where it is exposed in this township (see sections 8 and 9, Pl. XVII) and is thicker farther south. About 25 feet above bed C there is a bed containing about $3\frac{1}{2}$ feet of lignite (bed D), exposed at location 12, in sec. 32. The section measured at this place is shown in Plate XVII. About 4 feet of lignite at location 13, sec. 31, is in a bed probably bed E) about 60 feet higher than bed C and is also shown in Plate XVII.

T. 152 N., R. 95 W.

Only a part of secs. 12, 13, 24, 25, and 36, T. 152 N., R. 95 W., was examined. This area is a narrow strip less than a mile wide and about $4\frac{1}{2}$ miles long which lies within the reservation. The southern part is traversed by a tributary of Clark Creek, which has cut a deep trough into the lignite-bearing strata, exposing them in bluffs on either side. In the remainder of this belt the land is rolling and grass covered.

Bed C, which crops out extensively in the township immediately to the southeast, is not exposed in this township but probably underlies the greater part of it within 300 feet of the surface.

Three beds of lignite were mapped and measured in secs. 25 and 36. These beds occupy positions above bed C and correspond to beds D, E, and F, which were mapped also in the townships immediately to the south and southeast. Their general relations are shown in section 1, Plate XVI.

Lignite sections 22 and 23, Plate XVII, representing bed D, show that it contains about 3 feet of lignite. A satisfactory measurement of bed E could not be obtained in this township, owing to the fact that springs issue from the bed wherever it is exposed. At location 21, however, 2 feet of lignite was found above the surface of the water in a spring.

Bed F ranges in thickness from about 3 to 6 feet, as shown by sections 14 to 19, inclusive, on Plate XVII. At location 20 bed F contains 1 foot 8 inches of lignite, but owing to a slump at this place the measurement is not reliable.

T. 151 N., R. 93 W.

Only a small part of T. 151 N., R. 93 W., is included in the territory here described. This part lies in the flood plain of Missouri River and contains no exposures of lignite. It is probable, however, that the land is underlain by beds of lignite lower in the formation than those exposed along the river bluffs in this vicinity—such, for example, as bed A, mapped along the river in Tps. 150 and 151 N., R. 94 W.

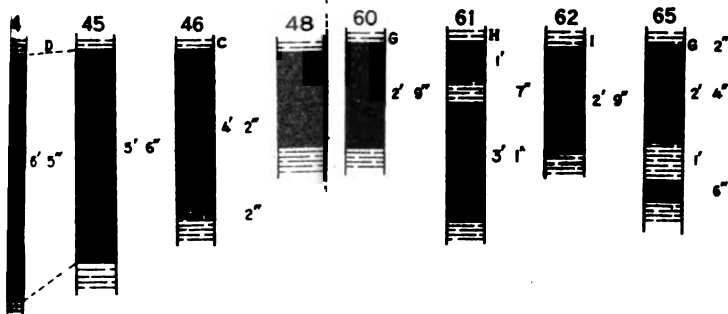
T. 151 N., R. 94 W.

Practically all of T. 151 N., R. 94 W., lies west of Missouri River and is included in the area described in this report. The eastern tier of sections, except sec. 1, is crossed by the river. The northern part of the township is deeply incised by Clark Creek and its tributary gullies, which have produced extensive badlands. The upland is very irregular in outline, and level portions of it are of small extent and confined largely to the southern and western parts of the township. Surmounting the upland in secs. 28, 29, 32, and 33 are high buttes, reaching altitudes of over 2,600 feet above sea level, or 870 feet above Missouri River. These buttes, known locally as the East Buttes, are part of a group of hills called the Blue Buttes, which lie largely west of the reservation. The upland in this township is thinly covered by glacial drift. Along the streams where erosion has been most rapid the lignite-bearing strata are well exposed. Altitudes on the lignite beds indicate a general eastward dip of about 8 feet to the mile. In secs. 1 and 12 this increases to about 75 feet to the mile in a northeasterly direction, and in secs. 25 and 26 a dip to the southeast of about the same magnitude was determined. As the relief is about 800 feet in this township, opportunity is offered for measuring long stratigraphic sections. One of these (section 1, Pl. XVI) shows the approximate position and relation of the lignite beds. There are fourteen of these beds exposed in the valley of Clark Creek and its tributaries, but only nine were considered of sufficient thickness to warrant mapping. The lowest bed that is exposed in the Fort Berthold field (bed A) crops out on the bluff facing Missouri River at location 98, in sec. 24, where it has a thickness of 10 feet (Pl. XVII). A measurement of an incomplete section of the same bed was made at location 103, in sec. 25, where it is more than 5 feet 7 inches thick. Elsewhere in the township the outcrop of this bed is covered with alluvium.

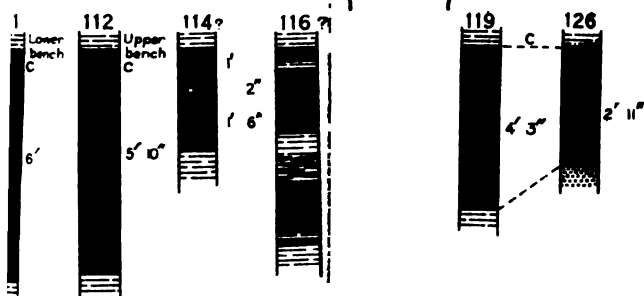
The next higher bed of lignite (bed B) is separated from bed A by 25 to 60 feet of sandy shale. Bed B is variable in thickness, and the lignite varies from place to place in quality. The bed crops out along Clark Creek and Missouri River and was measured at locations 30, 32, 36, 38, 39, 40, 41, 48, 52, 54, and 110. At location 110, in sec. 36, the following section was measured:

BULLETIN 726 PLATE XVII

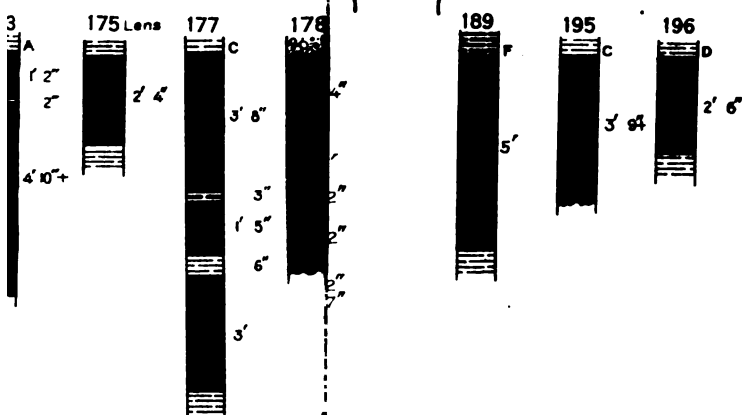
51 N., R. 94 W.



T. 150 N., R. 94 W.



T. 149 N., R. 95 W.



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Section of lignite bed at location 110, sec. 36, T. 151 N., R. 94 W.

Shale, carbonaceous.	Ft.	in.
Lignite, high in ash	1	10
Shale		5
Lignite	1	6
Shale.		
	3	9

The bed ranges in thickness from 2 feet at location 40, sec. 4, to 8 feet 10 inches at location 38, sec. 3; but its average thickness in this township is about 3 feet 8 inches. Plate XVII contains graphic sections of these beds, except that at location 110.

The next higher bed of lignite (bed C) is separated from bed B by about 70 feet of shale. It is represented on Plate XVII by sections 24, 26, 27, 28, 29, 31, 33, 37, 42, 46, 51, 53, 56, 86, 87, 89, 90, 91, 94, 95, 97, 99, 100, 101, 102, 104, 105, 108, 109, 111, and 112. The bed ranges in thickness from 2 feet at location 37, sec. 3, to almost 9 feet at location 51, sec. 6, but averages somewhat less than 5 feet. It is persistent and crops out for many miles along Missouri River, Clark Creek, and Bear Den Creek. It is separated into two benches in sec. 35, as shown by sections 101, 102, 108, 109, 111, and 112. The measurements on the bed in this locality are shown graphically in figure 15 (p. 126). Section 104 represents the entire bed, sections 108 and 111 the lower bench, and sections 109 and 112 the upper bench. In sec. 12 of the township immediately to the south, this bed was measured at location 119, where it consists of a single bench. The separation of lignite beds into two benches by partings of variable thickness is common to many of the beds of this region, and the sections shown in figure 15 are illustrative of this feature.

Bed D is about 25 feet above bed C in this township and is represented by sections 34, 35, 43, 44, 45, 47, 49, 50, 57, 78, 79, 80, 81, 82, 83, 84, 85, 88, 92, 93, and 96. All these sections except those given in the following table are shown on Plate XVII. Lignite sections 25 and 106 probably also represent this bed. Its average thickness is 3 feet.

Sections of lignite bed D in T. 151 N., R. 94 W.

[In addition to those shown on Pl. XVII.]

No. on map (Pl. XXVII).	Location.	Section.	
25.....	NE. $\frac{1}{4}$ sec. 1.....	Shale.	Ft. in.
		Lignite.....	1 3
		Shale.	
34.....	NW. $\frac{1}{4}$ sec. 2.....	Lignite.....	1 2
35.....	NE. $\frac{1}{4}$ sec. 3.....	Lignite.....	8
47.....	NE. $\frac{1}{4}$ sec. 5.....	Lignite, crushed.....	1±
97.....	NW. $\frac{1}{4}$ sec. 24.....	Lignite (bed D is 30 feet above bed C at this place).....	3 3
106.....	NW. $\frac{1}{4}$ sec. 35.....	Lignite.....	1 3

Bed E, about 38 feet above bed D, was measured at locations 55, 58, and 83 and averages about $4\frac{1}{2}$ feet in thickness in this township. All these sections are shown on Plate XVII.

A higher bed of lignite (bed F) averaging only $1\frac{1}{2}$ feet was measured at locations 59, 71, and 107. Section 71 is given on Plate XVII.

Sections of lignite bed F in T. 151 N., R. 94 W.

[In addition to that shown on Pl. XVII.]

No. on map (Pl. XXVII).	Location.	Section.	
			Ft. in.
59.....	SE. $\frac{1}{4}$ sec. 7.....	Lignite.....	1 6
107.....	NE. $\frac{1}{4}$ sec. 35.....	Lignite.....	1 2

Beds G, H, and I crop out in secs. 18 and 19 of this township. Measurements taken at locations 60, 65, and 70, shown on Plate XVII, averaging 2 feet 9 inches, are on bed G; those at locations 61, 66 (Pl. XVII), and 69, bed H. The section at location 69 shows several thin beds of lignite, as follows:

Section of lignite bed H at location 69, sec. 19, T. 151 N., R. 94 W.

Shale.....	Ft. in.
Lignite.....	6
Shale, carbonaceous.....	10
Lignite.....	6
Shale, carbonaceous.....	8
Shale.....	4
Sandstone.....	1
Lignite.....	6
Sandstone.....	3
Sandstone, carbonaceous.....	2
Shale.....	14
Lignite (bed H).....	1 8
Shale.....	37 10

Bed I was measured at locations 62, 67, and 68. These sections, averaging about 3 feet, are given on Plate XVII. A number of thin, unimportant beds of lignite which were measured at locations 114, 116, 117, and 118, in secs. 33 and 34, are shown graphically in section 1, Plate XVI, with their approximate correlation. Sections 114 and 116 are also shown on Plate XVII.

T. 151 N., R. 95 W.

The eastern part of T. 151 N., R. 95 W., which lies within the reservation, comprises a strip less than 1 mile wide and about 6 miles long. This strip of land is crossed by Clark Creek, whose steep valley walls expose the strata of the lignite-bearing Fort Union forma-

tion. Many of the lignite beds mapped in the township immediately to the east along Clark Creek were also mapped in this township. Beds A, B, C, and D lie too deep to be prospected except with a drill, hence their thickness is not known. The lowest lignite bed that crops out in this part of the township is bed E, which at location 73 is about 6 feet thick. (See Pl. XVII.) Bed F is 1 foot 3 inches thick at location 64, 2 feet at location 72,^o and 1 foot 11 inches at location 74. A measurement obtained at location 75 shows 2 feet 9 inches of lignite in bed G. Bed H is partly burned at location 76, the only exposure of it in this vicinity, where the following section was measured:

Section of lignite bed at location 76, sec. 24, T. 151 N., R. 95 W.

Shale.	Ft.	in.
Lignite-----	10	
Ash-----	10	
Shale.	1	8

Bed J was measured at location 77, in sec. 24, where it contains 1 foot 10 inches of lignite.

T. 150 N., R. 91 W.

Only a small part of T. 150 N., R. 91 W., is south of Missouri River, and this part lies almost entirely on the flood plain of the river. South of the flood plain is a low grass-covered bluff that rises about 65 feet to the rolling upland, which stretches southward. Glacial drift forms the surface in many places, but its maximum thickness is apparently only a few feet. Only one bed of lignite (bed E) crops out in the township. Measurements on this bed were obtained at locations 356, sec. 31, and 357, sec. 32, as given on Plate XX, and show that the thickness of the bed ranges in a distance of half a mile from 5 feet 1 inch to 3 feet 3 inches. It is believed that bed A, which in T. 151 N., R. 94 W., and adjoining townships has an average thickness of nearly 8 feet, lies beneath this part of T. 150 N., R. 91 W., at a depth of less than 300 feet. It is also probable that either one or all of beds B, C, and D, which lie too deep to be prospected without the aid of a drill, are thick enough to be of commercial value.

T. 150 N., R. 92 W.

Only a small part of T. 150 N., R. 92 W., lies south of Missouri River, and most of this part is in the flood plain of the river. Two beds of lignite crop out in the bluff in sec. 31. The lower of these, bed E, was measured at location 249, where it is 1 foot 4 inches thick. A section of the upper bed was not obtained in this town-

^o On Plate XVII sections 72 and 73 are erroneously connected by correlation lines.

ship, but it was measured in the township immediately to the south, where it has an average thickness of about 3 feet.

T. 150 N., R. 93 W.

T. 150 N., R. 93 W., is crossed by Missouri River from west to east, and only the part south of the river is here described. A prominent bluff rises abruptly from the river in the western part of the township and from the flood plain in the eastern part to a height of about 150 feet. This bluff has been dissected by the run-off of rains into a fringe of gullies, breaks, ridges, and points. The rough topography here affords an excellent opportunity for measuring and tracing the outcrops of lignite beds. The strata have a slight eastward dip of about 18 feet to the mile, as determined by a comparison of altitudes on the lignite beds. Four beds of lignite (beds A, C, E, and F) were mapped here, of which bed C is the most valuable. A partial section of bed A was obtained at an exposure at location 124, in sec. 18, near the water's edge of Missouri River. The entire thickness could not be measured, as part of the bed was beneath the water and only 1 foot 8 inches above. This bed, however, crops out extensively along Bear Den Creek in the township immediately to the west and has been found to have an average thickness of nearly 8 feet. Bed A, east of location 124, is lower than the surface of Missouri River.

Bed B contains at location 122 only 8 inches of lignite, between beds of carbonaceous shale.

Bed C is about 55 feet above bed B in this township and crops out almost continuously along the river bluff across the township. Beginning in the northwestern part of the township the sections of this bed are as follows: Nos. 120, 121, 123, 199, 200, 201, 202, 203, 208, 209, 210, 211, 212, 213, 214, 215, 226, 230, 232, 233, 234, and 235. The average thickness of bed C, as shown by these sections, is about 3 feet. Its maximum thickness, at location 202, in the SW. $\frac{1}{4}$ sec. 20, is 4 feet 2 inches. The more important sections listed above are shown on Plate XX, and the remainder are given in the following table:

Sections of lignite bed C in T. 150 N., R. 93 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVII).	Location.	Section.	Ft. in.	
199.....	NW. $\frac{1}{4}$ sec. 20.....	Lignite.....	1	1
200.....	NW. $\frac{1}{4}$ sec. 20.....	Lignite.....		8
213.....	SW. $\frac{1}{4}$ sec. 27.....	Shale.....		
		Bone.....	1	2
		Shale.....	1	6
		Lignite.....	1	
		Shale.....		

Sections of lignite bed C in T. 150 N., R. 93 W.—Continued.

No. on map (Pl. XXVII).	Location.	Section.	
215.....	NW. $\frac{1}{4}$ sec. 34.....	Shale.....	<i>Ft. in.</i>
		Shale, carbonaceous.....	1
		Lignite.....	4
		Shale, carbonaceous.....	1
		Bone.....	8
		Shale, carbonaceous.....	2
		Shale.....	25
		Lignite (bed C).....	6
		Shale.....	18
		Lignite.....	6
		Shale.....	
222.....	NE. $\frac{1}{4}$ sec. 35.....	Shale.....	
		Shale, carbonaceous.....	4
		Bone.....	1
		Lignite.....	8
		Shale.....	1
223.....	NW. $\frac{1}{4}$ sec. 36.....	Lignite, weathered.....	1

Sections 204, 205, 206, 207, 228, 229, and 231 represent a bed of lignite higher than bed C, probably bed D. The lignite is of poor quality and contains many partings of shale and bone, as shown in the sections which are given on Plate XX.

A bed of lignite averaging 2 feet 2 inches in thickness and lying approximately 145 feet higher than bed C was measured at locations 216, 218, 223, 225, and 227 and is probably bed E, though the correlation can not be made with certainty. These sections are given on Plate XX, with the exception of Nos. 223 and 225.

Sections of lignite bed E in T. 150 N., R. 93 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVII).	Location.	Section.	
223.....	SW. $\frac{1}{4}$ sec. 35.....	Lignite.....	<i>Ft. in.</i>
225.....	SW. $\frac{1}{4}$ sec. 35.....	Lignite.....	1
		Lignite.....	9
		Lignite.....	1

Bed F is separated from bed E by 25 to 35 feet of yellow sandstone, which is fairly regular in thickness and color and which was used as a marker in locating beds E and F in this township and townships farther east. Bed F was measured at locations 217, 219, 220, 222, and 224 (see Pl. XX) and averages about 2 $\frac{1}{2}$ feet in thickness.

A bed of lignite higher in the section in this township, which is believed to be bed G, was measured at location 221, in sec. 35, where it contains 3 feet 6 inches of good lignite. (See Pl. XX.)

T. 150 N., R. 94 W.

All of T. 150 N., R. 94 W., is included in the area described in this report, except a small tract in the eastern part of sec. 1 and the NE. $\frac{1}{4}$ sec. 12, which lies in the flood plain of Missouri River. West of the flood plain the bluffs rise over 125 feet to a rolling upland which

gradually increases in altitude away from the river. Farther west the upland is broken across the central part of the township by the deep valley of Bear Den Creek. Along this valley and also that of Missouri River badlands are developed in which the lignite-bearing strata are well exposed, and the beds of lignite are easily measured at many places. Only four beds, A, B, C, and D, were mapped continuously in this township.

Bed A has an average thickness of nearly 8 feet, as shown in sections 147, 151, 152, 158, 173, 178, 180, and 181 on Plate XVII. This thick bed of lignite is low in the strata exposed and probably underlies most of the township, as well as a considerable portion of the adjoining townships.

Bed B is separated from bed A by 40 feet of argillaceous sandstone. It contains very poor lignite and in many places has been found to be merely a bed of carbonaceous shale. Sections 157 and 159 of this bed are shown on Plate XVII. Its best development is at location 157, where the lower bench and the only one to be considered is 2 feet 8 inches thick; other measurements of it are given in the following table:

Sections of lignite bed B in T. 150 N., R. 94 W.

[In addition to section 157, Pl. XVII.]

No. on map (Pl. XXVII).	Location.	Section.	
148.....	SW. $\frac{1}{4}$ sec. 15.....	Lignite, impure.....	<i>Ft. in.</i> 5 6
153.....	NW. $\frac{1}{4}$ sec. 16.....	Shale. Lignite.....	1 2± 3 8
		Shale, carbonaceous.....	
		Shale.....	
174.....	NW. $\frac{1}{4}$ sec. 17.....	Lignite.....	1 3
184.....	NE. $\frac{1}{4}$ sec. 30.....	Lignite.....	1 8

Bed C, which averages over 5 feet in thickness, is about 70 feet above bed B in this township and was measured at locations 119, 126 to 135, 137, 138, 140, 142, 149, 150, 154 to 156, 160 to 164, 167, 168, 170 to 172, 177, 179, and 183. These sections, except Nos. 128, 150, and 154, are shown graphically on Pl. XVII.

Sections of lignite bed C in T. 150 N., R. 94 W.

[In addition to those shown on Pl. XVII.]

No. on map (Pl. XXVII).	Location.	Section.	
128.....	NW. $\frac{1}{4}$ sec. 24.....	Lignite.....	<i>Ft. in.</i> 1 6
150.....	SW. $\frac{1}{4}$ sec. 16.....	Lignite (base not exposed).....	2 6+
154.....	NE. $\frac{1}{4}$ sec. 16.....	Shale. Lignite.....	8 3 11
		Bone.....	
		Shale.....	

The outcrop of bed D, which in this township is about 90 feet higher than bed C, was mapped for a short distance, and measurements were obtained at locations 125, 136, 139, 141, 143, 145, 146, and 185. As shown by the sections, this is an unpromising bed, containing on an average less than 2 feet of lignite. Sections 139 and 145 are shown on Plate XVII, and other measurements are given in the following table:

Sections of lignite bed D in T. 150 N., R. 94 W.

[In addition to those shown on Pl. XVII.]

No. on map (Pl. XXVII).	Location.	Section.	
			<i>Ft. in.</i>
125.....	NW. $\frac{1}{4}$ sec. 24.....	Lignite.....	1 2
136.....	NW. $\frac{1}{4}$ sec. 23.....	Shale.....	
		Lignite.....	1 2
		Shale, carbonaceous.....	1
		Lignite.....	4
		Shale.....	2 6
		Lignite.....	1
		Shale.....	5
		Lignite.....	7
		Shale.....	
141.....	SE. $\frac{1}{4}$ sec. 10.....	Lignite.....	1 3
143.....	SE. $\frac{1}{4}$ sec. 10.....	Lignite.....	1 4
146.....	NW. $\frac{1}{4}$ sec. 15.....	Lignite.....	1 6
185.....	SW. $\frac{1}{4}$ sec. 29.....	Lignite.....	1 2

Isolated outcrops of higher beds of lignite were measured at locations 165, 175, and 176. Sections 165 and 175 are shown on Plate XVII. The bed measured at location 176 carries 1 foot 11 inches of lignite and is probably the same bed as that at location 175. The relation of this bed to other beds is shown in stratigraphic section 2, Plate XVI. Other measurements of lignite beds were made at locations 114 and 166. The beds at both locations are impure; they contain 2 feet of lignite at location 144 and 2 feet 10 inches of lignite at location 166.

T. 150 N., R. 95 W.

That part of T. 150 N., R. 95 W., included in the Fort Berthold Reservation is a strip less than a mile wide along the eastern edge of the township. Along the steep bluffs of Bear Den Creek, which crosses this strip, four beds of lignite (A, B, C, and E) were mapped. No measurements were made on bed A in this township, but its average thickness in the township to the east is nearly 8 feet, and it probably underlies this township also. A measurement of bed B was obtained at location 186, sec. 25, where it contains 2 feet 3 inches of lignite, as shown on Plate XVII. Section 169, showing 5 feet 1

inch of bed C, is given on Plate XVII. Another bed of lignite about 125 feet higher in the section, which may be bed E, is represented by sections 182, 187, and 188, Plate XVII. At location 182 this bed contains 4 feet 4 inches of lignite, and at locations 187 and 188 ¹⁰ it is separated by a thick shale parting into two benches, each of which is over 2½ feet thick.

T. 149 N., R. 91 W.

The greater part of T. 149 N., R. 91 W., is a rolling upland covered thinly with glacial drift. The eastern part, however, includes a portion of the wide flood plain of Missouri River. The maximum relief within the boundaries of the township is about 450 feet. Throughout most of the township the strata have a slight dip to the northeast, but in secs. 35 and 36 there is an eastward dip of about 100 feet to the mile.

Six beds of lignite were mapped at several places in this township. Bed E is probably the most valuable, although bed CC, which is about 110 feet below bed E and at about the same position in the section as bed C, was mapped for a considerable distance in the eastern part of the township. Beds A and B lie too deep to crop out in this township, hence no data regarding them were obtained. Measurements of bed CC were obtained at locations 362, 367, 368, and 369. (See Pl. XX.) Sections 376 and 377 probably also represent the same bed. It is of fair quality and averages 3 feet in thickness. At location 377, in sec. 36, the bed carries at least 1 foot 8 inches of lignite, but the base could not be reached on account of the water from a spring at the outcrop.

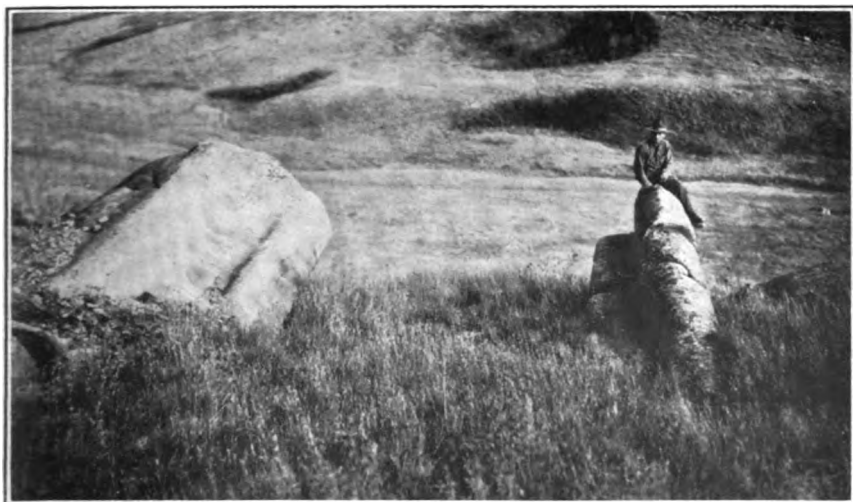
Bed E was mapped continuously along the bluffs in a northwest-southeast direction across the central part of the township. The sections of this bed are Nos. 353, 354, 355, 358, 359, 360, 361, 363, 365, 370, 372, 373, and probably also 378. At location 354 it contains 1 foot 11 inches of lignite. Southeast of this place it is generally thicker, but at location 370 it carries only about 8 inches of lignite. It is quite probable that the measurement at location 370 is not complete, as the lignite was much weathered and the shale above may not have been in place. At location 365 bed E carries 4 feet 2 inches of good lignite. Other sections of this bed are shown on Plate XX.

Measurements on a thin bed of lignite about 30 feet below bed E and near the horizon of bed D were obtained at a number of places, and its thickness is shown by sections 364, 374, and 375. Section 364 shows 1 foot 4 inches of lignite, and section 375 shows 1 foot 2 inches. Section 374 is shown on Plate XX.

¹⁰ Section 188 is erroneously labeled bed C on Plate XVII.



A. BARE BUTTES OF THE FORT UNION FORMATION ON THE SOUTH SIDE OF HANS CREEK, N. DAK.



B. LOG CONCRETIONS IN FORT UNION FORMATION.



A. GLACIAL BOULDERS ON THE UPLAND IN T. 147 N., R. 93 W., N. DAK.



B. BED OF LIGNITE 8 FEET THICK IN NATURAL EXPOSURE IN SEC. 14, T. 147 N., R. 93 W., N. DAK.

Bed F, which is about 40 feet above bed E, was measured at location 363 (see Pl. XX) and also at location 366, where it contains 1 foot 9 inches of lignite. A section obtained at location 371, containing 1 foot 9 inches of lignite, may also represent bed F.

Three beds of lignite from 100 to 180 feet higher in the formation than bed E were mapped in secs. 27, 28, 31, 32, and 33. These beds probably correspond to beds I, K, and M in the township to the south. In T. 149 N., R. 91 W. they are thin and variable in quality, but in the township to the south they have been traced continuously for long distances. Beds I and K were measured at location 382, where they are 2 feet 5+ inches and 2 feet 8 inches thick, respectively. Bed K carries 2 feet 4 inches of lignite at location 380. Bed M was measured at locations 379, 381, and 383, and the sections are given below:

Sections of lignite bed M in T. 149 N., R. 91 W.

No. on map (Pl. XXVII).	Location.	Section.	
			<i>Ft. in</i>
379.....	NW. $\frac{1}{4}$ sec. 27.....	Lignite.....	1 9
381.....	SW. $\frac{1}{4}$ sec. 33.....	Lignite.....	1 3
383.....	SE. $\frac{1}{4}$ sec. 32.....	Lignite.....	2

T. 149 N., R. 92 W.

All of T. 149 N., R. 92 W., except the northern parts of secs. 1, 2, and 3 is here described. The maximum relief in the township is about 525 feet. Excellent exposures of the stratified rocks occur in the bluffs and gullies along Missouri River and on both sides of the valley of Skunk Creek, which flows through the central part of the township. The course of the lower part of Skunk Creek apparently follows a shallow syncline.

Outcrops of lignite beds E and F were mapped almost continuously throughout this township. The beds are not constant in thickness, however, and both of them are thinner in the eastern part of the township than they are in the western part. Beds D and G were also measured in this township and mapped for short distances. The stratigraphic relations of these beds are shown in Plate XVI, section 4.

Several sections of lignite beds lower in the formation than bed E were obtained, but correlation of these beds is uncertain. Their thicknesses are given in the following table:

Sections of lignite beds below bed E in T. 149 N., R. 92 W.

No. on map (Pl. XXVII).	Location.	Section.	Ft. in.
281.....	SE. $\frac{1}{2}$ sec. 9.....	Lignite.....	1 9
297.....	SE. $\frac{1}{2}$ sec. 19.....	Lignite.....	1 3
302.....	NE. $\frac{1}{2}$ sec. 20.....	Shale.....	
		Lignite.....	1
		Shale, carbonaceous.....	8
		Lignite.....	5
		Bone.....	4
		Shale.....	
310.....	SW. $\frac{1}{2}$ sec. 15.....	Lignite.....	1 11
314.....	SE. $\frac{1}{2}$ sec. 15.....	Shale.....	
		Lignite.....	1 6
		Bone.....	1
		Lignite.....	6
		Shale, carbonaceous.....	1 7
		Shale.....	
345.....	NW. $\frac{1}{2}$ sec. 12.....	Lignite (bed D?).....	9
347.....	SE. $\frac{1}{2}$ sec. 2.....	Lignite.....	1 9
348.....	SW. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 2
352.....	NE. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 8

Sections 312, 313, and 346, averaging about 3 feet, probably represent bed D and are shown in Plate XX. All the preceding measurements were obtained on lenticular beds of lignite that occur at about the same horizon as bed D, but they can not be exactly correlated.

Bed E, the lower one of the beds mapped, has an average thickness of about 3 feet in this township. It was measured at locations 250, 253, 261, 276, 279, 280, 284, 285, 287, 290, 293, 294, 306, 309, 311, 315 to 317, 320, 322, 323, 325, 326, 330, 331, 333, 334, 338, 339, 341 to 344, 348, 350, and 351. Most of the sections of this bed are shown in Plate XX. Measurements of bed E not shown graphically are as follows:

Sections of lignite bed E in T. 149 N., R. 92 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XVII).	Location.	Section.	Ft. in.
250.....	NW. $\frac{1}{2}$ sec. 6.....	Bone.....	3 4
253.....	NW. $\frac{1}{2}$ sec. 6.....	Lignite.....	1 6
261.....	NW. $\frac{1}{2}$ sec. 5.....	Lignite.....	1 5
279.....	SW. $\frac{1}{2}$ sec. 10.....	Lignite.....	1 10
348.....	SW. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 0
350.....	SE. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 5
351.....	SE. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 4

Bed E is commonly separated from Bed F by 40 to 50 feet of yellow friable sandstone, which is easily distinguished from other beds of the formation in this locality.

Bed F, which is about 55 feet above bed E, is exposed at a great many places in this township with an average thickness of about 3 feet 2 inches. Its sections are Nos. 251, 254, 255, 258 to 260, 262 to 265, 269, 271 to 275, 277, 278, 282, 283, 285, 288, 291, 295, 296, 298, 307, 308, 318, 319, 321, 324, 327, 328, 329, 332, 335 to 337, 340, and 349. All these sections, except those measured where the bed was only partly exposed or was too thin to be workable, are shown on Plate XX. The other measurements are tabulated below:

Sections of lignite bed F in T. 149 N., R. 92 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVII).	Location.	Section.	Ft. in.
251	NW. $\frac{1}{4}$ sec. 6	Lignite	3 4
262	NE. $\frac{1}{4}$ sec. 5	Lignite	1 10
264	NE. $\frac{1}{4}$ sec. 5	Lignite	1 7
272	SE. $\frac{1}{4}$ sec. 4	Lignite (top of bed eroded)	1 2+
273	SW. $\frac{1}{4}$ sec. 3	Bone	1 5
274	NW. $\frac{1}{4}$ sec. 10	Lignite	1 6
277	SW. $\frac{1}{4}$ sec. 10	Lignite	1 8
282	SE. $\frac{1}{4}$ sec. 9	Lignite	1 3
337	SE. $\frac{1}{4}$ sec. 14	Lignite	1 8

Bed G, with an average thickness of 2 feet 8 inches, crops out in some of the higher parts of this township. It was measured at locations 252, 256, 257, 266, 267, 268, 286, 289, and 292. All these sections are shown graphically on Plate XX, except No. 268, which is given below.

Section of lignite bed at location 268, sec. 8, T. 149 N., R. 92 W.

Shale	Ft. in.
Lignite	4
Shale	1 7
Lignite	6
Shale	

At location 270 a bed of lignite, whose position is not known, has a thickness of 1 foot 5 inches.

T. 149 N., R. 93 W.

T. 149 N., R. 93 W., is a rolling upland, broken on the north by the badlands along Missouri River and on the south by Squaw Creek and its tributaries. The central part of this township contains very poor rock exposures, and no outcrops of lignite beds were found except in secs. 1, 2, 3, 4, 35, and 36, where beds D, E, and F were measured. The relations of these beds are shown in the stratigraphic sections on Plate XVI.

Bed D, the lowest one, is broken by shale partings as shown by the following section, and the lignite is poor:

Section of lignite bed D at location 243, sec. 1, T. 149 N., R. 93 W.

Shale.	Ft. in.
Bone.....	2
Lignite.....	1 9
Shale, carbonaceous.....	1 4
Bone.....	4
Shale.....	1
Shale, carbonaceous.....	6
Lignite.....	3
Shale.	

Bed E is exposed in the bluffs at many places, and sections were measured at locations 237, 238, 239, 240, 244, 247, and 248. All these sections except Nos. 244 and 248, given below, are shown in Plate XX. The average thickness of bed E obtained from these measurements is 2 feet 6 inches.

Sections of lignite bed E in T. 149 N., R. 93 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVII).	Location.	Section.
244.....	NE. $\frac{1}{4}$ sec. 1.....	Shale. Bone..... Lignite..... Shale.....
248.....	NE. $\frac{1}{4}$ sec. 1.....	Lignite.....

Bed F, which averages in this township a little over $2\frac{1}{2}$ feet in thickness, is 52 feet higher than bed E at location 245 and 25 feet higher at location 239. Measured sections of this bed at locations 236, 239, 241, 242, and 245 are shown on Plate XX.

At location 246, in sec. 1, bed G is 1 foot 10 inches thick. In secs. 32, 35, and 36 there is a bed of lignite at about the same position as bed I. However, no measurement, except at location 301 (see Pl. XX), was obtained on this bed, but in the township to the south, where it was mapped extensively, it was measured in many places and averages over 3 feet in thickness.

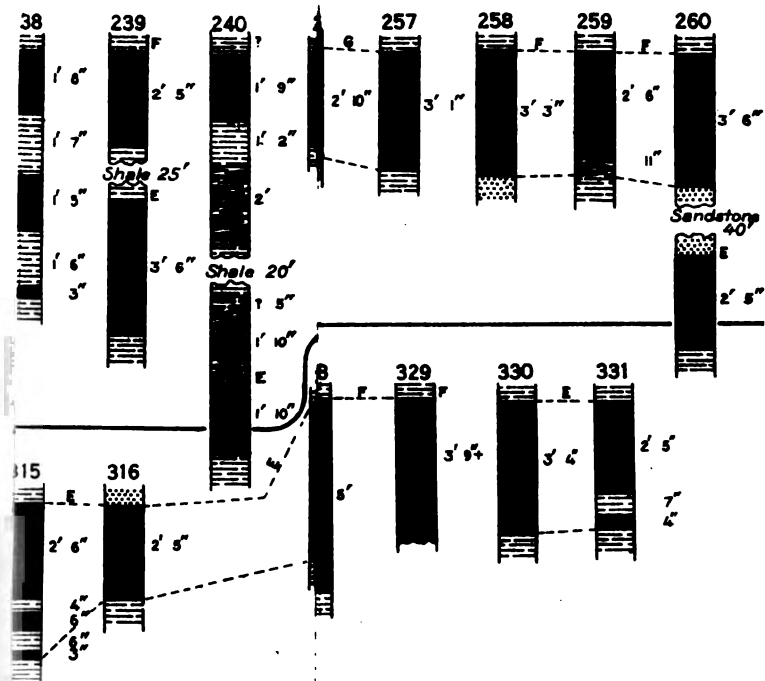
Another bed corresponding to bed K in the township immediately to the south was measured at locations 299 and 300, in sec. 36, and averages $4\frac{1}{2}$ feet in thickness, though its upper portion is bony at location 300. (See Pl. XX.)

Bed M was measured in a number of places in the township to the south and was mapped for a short distance in this township, although no section of it was obtained here.

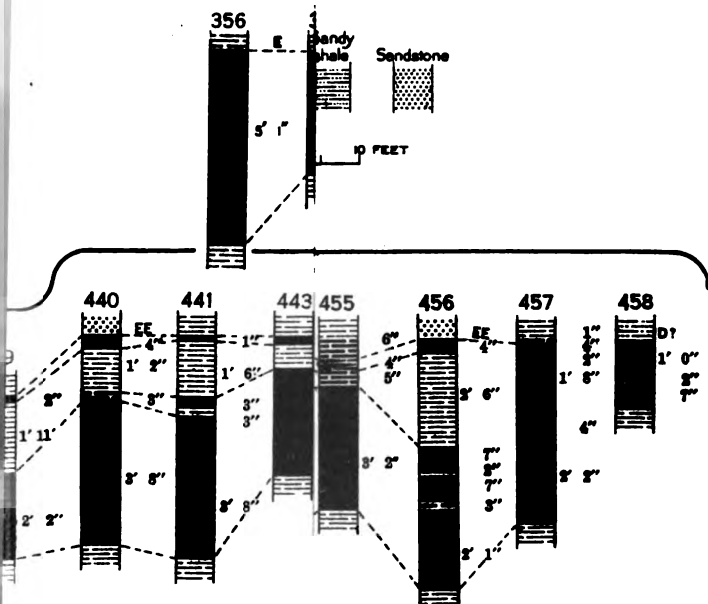
T. 149 N., R. 94 W.

T. 149 N., R. 94 W., is largely a grass-covered upland. Several streams head in the township, among them Squaw and Bear Den

N., R. 92 W.



T. 150 N. R.



TION, NORTH

creeks. The valleys, as shown in Plate XXV, A, are broad, with gentle slopes, and do not seem to have been affected by the advance of the ice sheet, although here and there erratic boulders are found. Most of the township is lacking in rock exposures, and outcrops of lignite beds were found only in a few localities in secs. 6 and 7. Section 194 represents a lenticular bed of lignite that lies between beds C and D and is 2 feet thick. Sections 191 and 193 represent bed D, which averages about $3\frac{1}{2}$ feet in thickness in this township. (See Pl. XVII.) Section 190 probably shows bed E, and sec. 192, bed F.

T. 149 N., R. 95 W.

The eastern part of T. 149 N., R. 95 W., comprising a strip of land less than 1 mile wide and about 6 miles long, is included in the Fort Berthold Reservation. The southern part of this strip is a high, rolling upland. The northern part lies in the valley of Bear Den Creek, which furnishes several good exposures of the lignite-bearing formation. Four beds of lignite (beds C, D, E, and F) that are exposed in the township immediately to the north crop out in this township also and were measured in the NE. $\frac{1}{4}$ sec. 12. Their thickness and general relations are given in stratigraphic section 3, Plate XVI, the upper 180 feet of which was measured on a butte just outside of the reservation. Location 195 is on bed C, 196 on bed D, 197 on bed E, and 198 on bed F. (See Pl. XVII.) At location 197 bed E contains 2 feet 1 inch of lignite separated into two equal benches by 3 feet of shale. The section at location 189, in the NE. $\frac{1}{4}$ sec. 1, represents bed F and is given on Plate XVII. At location 198 bed F contains 1 foot 2 inches of lignite.

T. 148 N., R. 91 W., NORTH OF LITTLE MISSOURI RIVER.

The part of T. 148 N., R. 91 W., lying north of Little Missouri River and west of Missouri River is here described. The part lying south of Little Missouri River is described on page 162. The eastern half of the area here described consists of the flood plain of Missouri and Little Missouri rivers. The western part of the township is a rolling upland about 150 feet above the river. Outcrops of stratified rocks are few and limited to small areas. Two beds of lignite crop out in secs. 4, 5, 8, and 9, and one bed in secs. 19 and 30. The lower bed mapped in this township (called bed CC?) is probably the same as the lowest bed mapped in the township to the north. It was measured only at location 386, in sec. 5, where it carries 2 feet 8 inches of lignite.

The next higher bed is correlated with bed E of the township to the north and was measured at locations 285 and 287. The bed

mapped in secs. 19 and 30 is probably bed E, as it has about the same position. However, owing to the uncertainty of the correlation, it is called bed EE. It was measured at locations 388, 389, and 390. Section 390 is shown on Plate XX; the other two are given below.

Sections of lignite bed EE in T. 148 N., R. 91 W.

[In addition to that shown on Pl. XX.]

No. on map (Pl. XXVIII).	Location.	Section.	Pl. No.
388.....	NE. $\frac{1}{4}$ sec. 30.....	Lignite.....	2 3
389.....	NW. $\frac{1}{4}$ sec. 30.....	Lignite.....	2 11

This bed becomes thicker toward the west and was mapped continuously in that direction for more than 25 miles.

T. 148 N., R. 92 W.

T. 148 N., R. 92 W., is drained by Squaw Creek and other small streams that flow into Little Missouri River. The valley of Squaw Creek is nearly as wide as the valley of the Little Missouri, though the creek is about one-tenth the size of the river. The central part of the township is a rolling upland dissected by the sharp, steep-sided valleys of southward-flowing intermittent streams. Near the north boundary of the township is a group of high buttes headed on the east by Saddle Butte. A spur of bare buttes extends southward from this group in the west-central part of the township. The relief is about 700 feet.

The general character and relation of the rocks in this township are shown in stratigraphic section 5, Plate XVI. The beds have a general eastward dip of about 12 feet to the mile. Minor structural features, such as a shallow syncline in sec. 16, a low dome in secs. 4 and 9 pitching rather steeply to the east in sec. 15, and a synclinal basin with its center in sec. 11, were determined by careful plane-table traverse on lignite bed I. However, the greatest observed dip in this township is less than 2°. A thin mantle of glacial drift covers the gentle slopes of Squaw Creek valley (Pl. XXV, A), and in the NE. $\frac{1}{4}$ sec. 33 glacial till was noted with a maximum thickness of 6 feet.

Four valuable beds of lignite are exposed in this township. Bed EE crops out along Little Missouri River and Squaw Creek, with an average thickness of 3 feet. Sections measured at locations 391, 392, 437, 439 to 447, and 449 to 457 show the character of this bed. These sections are shown graphically in Plate XX, except those at locations 391 and 442, at both of which bed EE carries 1 foot 10 inches of lignite.

A thin bed of lignite about 30 feet below bed EE was measured at locations 451¹¹ and 458. Its correlation with bed D is uncertain. The measurements are tabulated below.

Sections of lignite lens in T. 148 N., R. 92 W.

[Not included in Pl. XX.]

No. on map (Pl. XXVIII).	Location.	Section.	
			<i>Ft. in.</i>
451.....	SW. $\frac{1}{4}$ sec. 27.....	Lignite.....	2 6
458.....	SE. $\frac{1}{4}$ sec. 32.....	Lignite.....	1 7

A bed of lignite higher than bed EE and probably corresponding to bed F was measured at location 448, in sec. 26, where it contains 3 feet of lignite. This bed is about 40 feet above bed EE and carries lignite of poor quality.

A second bed of importance in the township is bed I, which is about 175 feet above bed EE. This bed is somewhat variable in thickness, but as shown by the measurements on Plate XX, it averages over 2 feet 6 inches of good lignite. It is represented by sections 393, 395, 397, 398, 400, 401, 405, 410, 416, 419, 420, 422 to 431, and 433 to 436, all of which except those tabulated below are given on Plate XX.

Sections of lignite bed I in T. 148 N., R. 92 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVIII).	Location.	Section.	
			<i>Ft. in.</i>
395.....	NE. $\frac{1}{4}$ sec. 13.....	Lignite.....	1 11
416.....	NE. $\frac{1}{4}$ sec. 11.....	Lignite.....	1 9
420.....	NE. $\frac{1}{4}$ sec. 14.....	Lignite.....	1 9
423.....	NE. $\frac{1}{4}$ sec. 15.....	Shale, carbonaceous.	
		Lignite.....	1 4
		Shale.....	9
		Lignite.....	4
		Shale.....	

Bed K, which lies about 80 feet above bed I, was mapped in the northeastern part of this township and also in sec. 18. It has an average thickness of about 2 feet and is represented by sections 394, 396, 399, 404, 406, 409, 417, 418, 421, and 432. These sections are shown graphically on Plate XX, with the exception of those given in the following table:

¹¹ On Plate XX section 451 is erroneously credited to bed EE, whereas it represents a bed 30 feet below bed EE.

Sections of lignite bed K in T. 148 N., R. 92 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVIII).	Location.	Section.	
			<i>Ft. in.</i>
396.....	SE. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 9
399.....	SW. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 8
404.....	SW. $\frac{1}{2}$ sec. 1.....	Lignite.....	1 6
417.....	SW. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 5

Bed M is about 25 feet above bed K and is thick enough to warrant mapping (2 feet or more) only in secs. 1, 2, 3, 11, and 12. Measurements of this bed were obtained at locations 402, 403, 407, 408, 411, 412, 413, 414, and 415, and are shown graphically on Plate XX, with the exception of those which are tabulated below.

Sections of lignite bed M in T. 148 N., R. 92 W.

[In addition to those shown on Pl. XX.]

No. on map (Pl. XXVIII).	Location.	Section.	
			<i>Ft. in.</i>
412.....	NW. $\frac{1}{2}$ sec. 2.....	Lignite.....	1 4
414.....	NW. $\frac{1}{2}$ sec. 11.....	Lignite.....	1 5
415.....	NE. $\frac{1}{2}$ sec. 11.....	Lignite.....	1 8

A stratigraphic section including about 300 feet of strata was measured in a butte at location 438. Two beds of lignite, corresponding to beds I and K of the townships farther north, were found. Both were less than 2 feet thick at this place.

T. 148 N., R. 93 W.

T. 148 N., R. 93 W., is traversed diagonally from northwest to southeast by the broad valley of Squaw Creek, which at its upper ends opens out into the broad flat of the upland, as shown in Plate XXV, *A*, but which lower down in this township is bordered by badlands that give it a much more rugged appearance. A group of these buttes in sec. 9 is shown in Plate XXIV, *A*, and another group exhibiting typical topography of the western part of the reservation is shown in Plate XXIV, *B*.

The lignite-bearing rocks are very well exposed along Moccasin Creek and in the high buttes on the north side of Squaw Creek. The southern exposures, as shown in Plate XXV, *B*, are much better than those on the hillsides facing the north. This seems to be due partly to the lodging of glacial drift and partly to the greater abundance of vegetation on the northern slopes. The general dip of the strata in this township is about 12 feet to the mile N. 70° E., but there are

many minor undulations in the beds which cause local dips in various directions. A low anticline with its axis approximately in secs. 8 and 9 and a shallow syncline with its axis in sec. 14 were determined by comparing altitudes on the lignite beds. None of the observed dips exceed 2° . A thin mantle of glacial drift forms the surface over most of the highland and in a few of the larger valleys. In the NW. $\frac{1}{4}$ sec. 27 a section of glacial drift 12 feet thick was measured. The drift contains at this place principally limonite concretions, boulders of sandstone and shale, and pebbles of limestone, granite, and quartzite. The whole is loosely cemented with gypsum and limonite.

Five beds of lignite were mapped in this township, but none of them is thick enough to justify mapping all along its outcrop. Bed EE, the lowest bed exposed, was measured only at locations 524 and 525, in sec. 36. At location 524 this bed contains less than 12 inches of lignite, and at location 525 it carries 3 feet 3 inches of lignite. In the township immediately to the south, where this bed is much thicker, its outcrop has been mapped for long distances.

Bed FF is poorly exposed, and where it crops out it is too thin to be of value.

Bed I in this township is about 150 feet higher than bed EE, and its average thickness is about 3 feet. Sections 459, 463, 464, 465, 469, 474, 475, 479, 486, 487, 492, 493, 494, 497, 499, 500, 502, 506, 507, 509, 516, 519, 520, and 521 (Pl. XXIII) represent this bed. At location 465, in sec. 13, this bed contains 2 feet 3 inches of impure lignite; at location 494, in sec. 4, 1 foot 10 inches of lignite. Section 522, showing nearly 4 feet of lignite, is probably on the same bed but could not be identified with certainty. A lenticular bed of lignite about 25 feet above bed I was measured at location 473, where it is 2 feet thick. Both east and west of this place this bed is thinner. Section 481 represents a worthless bed somewhat higher than bed I, which may correspond to bed J.

Bed K, which has an average thickness of about 3 feet, is represented by sections 468, 471, 476, 480, 485, 489, 491, 495, 498, 501, 503, 505, 508, 512, 515, 517, 518, and probably also 523. These are shown graphically on Plate XXIII. At location 523 a bed of lignite is 1 foot 2 inches thick.

Sections 460, 461, 466, 470, 472, 477, 482, 484, 488, 490, 496, 504, 510, 511, 513, and 514 represent bed M. (See Pl. XXIII.) This bed contains 1 foot 11 inches of lignite at location 496, but its average thickness is 3 feet 6 inches. Bed N, the highest bed of lignite stratigraphically that is mapped in this township, is represented by sections 467, 478, and 483. It is lenticular, but in its lower part the lignite is of very good quality and averages 2 feet 10 inches in thickness.

Good exposures of the rocks occur in secs. 34 and 35, but they are noticeably lacking in beds of lignite. The strata here are composed mainly of yellow sandstone and gray clayey sandstone.

T. 148 N., R. 94 W.

T. 148 N., R. 94 W., lies largely on the upland, which is surmounted here and there by buttes 200 to 300 feet high. Exposures of the lignite-bearing formation are confined almost entirely to the few isolated hills and the badlands in sec. 31. The strata apparently lie nearly flat. Only one lignite section was obtained in the township, at location 636, in sec. 27, where a bed of lignite 2 feet 10 inches thick crops out in a tributary of Moccasin Creek. It is probable that the bed which was mapped in sec. 31 underlies most of this township and may be the same as the bed mapped in secs. 1 and 12. The strata exposed in the high hills in this township seem to be barren of lignite.

T. 148 N., R. 95 W.

That part of T. 148 N., R. 95 W., that lies within the Fort Berthold Reservation is described here. The lignite-bearing rocks are very well exposed in this township, especially in the almost vertical cliffs in the badlands along Sams Creek. Two valuable beds of lignite and numerous thin beds crop out here. The lowest one is probably bed EE, whose average thickness is about 12 feet. It is represented by sections 627, 628, and 631, Plate XXIII. Owing to the burning of the outcrop it is generally concealed by clinker. A lenticular bed about 2 feet 10 inches thick and 20 feet higher (bed FF ?) was measured at location 632. Another thin bed (bed HH) was measured at location 633, where it contains 2 feet 4 inches of impure lignite. Bed I-J, with an average thickness of 3 feet 10 inches, crops out for some distance in this township and is represented by sections 626, 629, 630, 634, and 635, Plate XXIII. At location 635 the bed is composed principally of shale, as shown below.

Section of lignite bed I-J at location 635, sec. 27, T. 148 N., R. 95 W.

Shale.	Ft.	in.
Bone	2	1
Shale		8
Lignite		5
Shale		3
Lignite	1	3
Shale.		
	4	8

Several beds of lignite were noted in the northern part of the township, but as they are less than 2 feet thick they were not mapped.

T. 147 N., RS. 92 AND 93 W., WEST OF LITTLE MISSOURI RIVER.

The parts of T. 147 N., Rs. 92 and 93 W., that are here described lie north and west of Little Missouri River. (See Pl. XXVIII.) These contiguous townships are described together because of the similarity of their surfaces and the continuity of outcrops of lignite beds from one to the other. That part of the townships adjacent to the Little Missouri contains some of the roughest badlands in North Dakota. Views of these badlands in secs. 25 and 26 are shown in Plate XIV. They are generally without vegetation and thus afford excellent exposures of the lignite-bearing formation. The southern slopes are almost free of vegetation, but the northern slopes are commonly covered with grass, and some of the coulees contain a dense growth of scrub pines. In sec. 6, T. 147 N., R. 92 W., the badlands are not so prominent as farther south, and the valley of Moccasin Creek, as shown in Plate XV, *B*, is broad and has comparatively gentle slopes.

In sec. 19, T. 147 N., R. 93 W., there is a flat tract on which the glacial boulders shown in Plate XIX, *A*, are scattered in great numbers. At several places blocks of granite a yard or two in length lie upon the surface.

The dip of the beds is about 8 feet to the mile in a southeasterly direction, as determined by stadia traverse on the lignite beds. Eight beds of lignite of sufficient thickness to justify mapping crop out in these two townships, and owing to the excellent exposures in the badlands most of the lignite beds can readily be studied in detail. The stratigraphic position of lignite beds in these townships is shown in section 7, Plate XVI.

The lowest bed stratigraphically is at about the same horizon as bed DD and crops out in several localities, but is not thick enough to justify mapping except at location 594, in sec. 20, T. 147 N., R. 93 W., where it contains 3 feet 2 inches of good lignite. West of this place the bed is burned on the outcrop for a short distance, and beyond the burned area it is covered by alluvium of the river flood plain. At location 579 the following section of this bed was measured:

Section of lignite bed at location 579, sec. 28, T. 147 N., R. 93 W.

Shale.	Ft.	in.
Lignite.....	1	
Shale.....	9	
Lignite.....	1	3
Shale.		
	11	3

Bed EE, which is perhaps the most persistent and valuable bed in these townships, is about 30 feet above bed DD. In the NW. $\frac{1}{4}$ sec. 1, T. 147 N., R. 93 W., it is less than 30 inches thick, but east and

south of this place it generally measures 3 feet or more. It is represented on Plate XXIII by sections 526 to 531, 542, 549, 569, 573, 578, 591, and 595.

The greater part of the outcrop of bed EE is covered by clinker, and as it crops out near the bases of talus slopes it is also covered in many places by débris from the weathering of younger strata.

A thin bed of lignite about 20 feet above bed EE was measured at locations 550, 583, and 598, in T. 147 N., R. 93 W. At location 550 it carries 10 inches of lignite; at location 583, 2 feet; and at location 598, 1 foot 9 inches.

The beds of lignite higher in the formation can not be certainly correlated with those in the northern part of the Fort Berthold field; therefore double letters are used to designate the beds. Bed GG, which is at about the horizon of bed G, has a more sinuous outcrop than any other lignite bed in these townships and is also the best exposed, as it crops out at an altitude where rapid erosion is in progress. It is fairly constant in thickness, averaging about 5 feet, but contains a high percentage of ash. It is present at locations 535, 541, 551, 557, 559, 560, 563, 576, 577, 580, 584, 585, 590, 596, 597, and 599, in T. 147 N., R. 93 W.; and locations 564 and 572, in T. 147 N., R. 92 W. The sections at these locations are shown graphically on Plate XXIII, with the exception of section 535, which includes only 10 inches of lignite.

Bed HH is generally separated from bed GG by 20 to 35 feet of yellow sandstone. It occurs at locations 540, 543, 546, 565, and 571, in T. 147 N., T. 92 W.; and locations 534, 537, 552, 558, 561, 577, 586, 588, and 589, in T. 147 N., R. 93 W. (See Pl. XXIII.) Its average thickness is nearly 4 feet.

Bed II is represented in T. 147 N., R. 92 W., by sections 545 and 568, and in T. 147 N., R. 93 W., by sections 539, 548, 553, 577, and 592 (Pl. XXIII); it averages about 3 feet in thickness.

Bed JJ is mapped for a considerable distance in these townships. It lies in a zone of shale and in some places contains a small amount of gypsum. This bed occurs at locations 544, 566, and 570, in T. 147 N., R. 92 W., and locations 532, 533, 536, 538, 547, 554, 562, 581, 582, and 587, in T. 147 N., R. 93 W. The sections at these locations, with the exception of those tabulated below, are shown graphically on Plate XXIII.

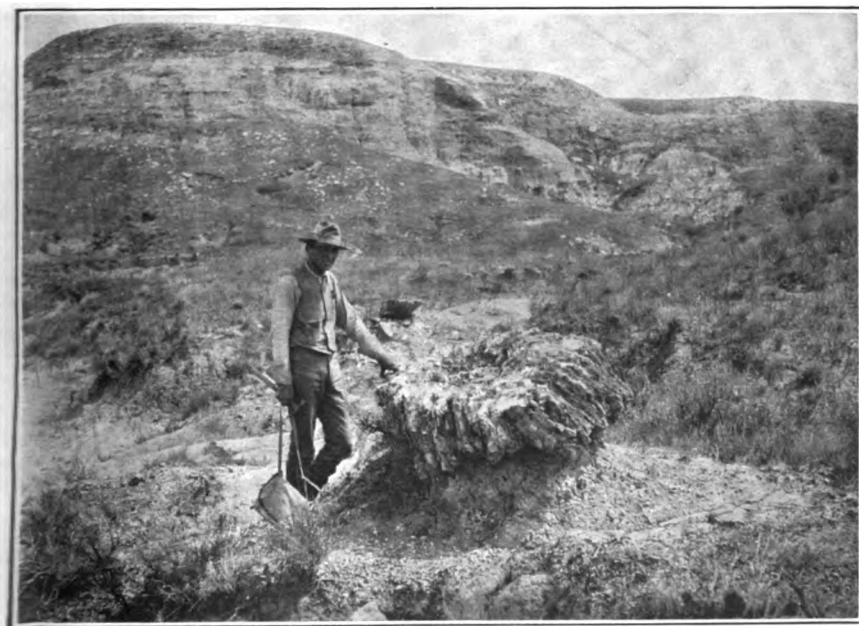
Sections of lignite bed JJ in T. 147 N., Rs. 92 and 93 W.

[In addition to those shown on Pl. XXIII.]

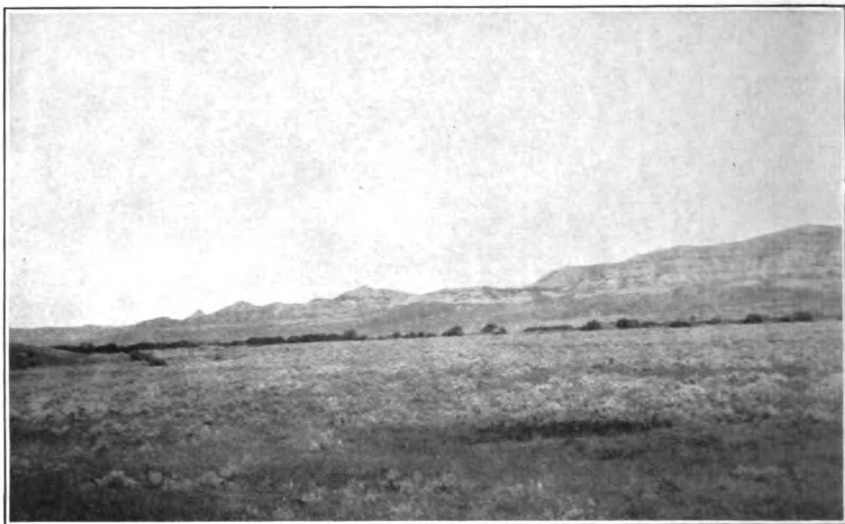
No. on map (PL. XXVIII).	Location.	Section.	
546.....	SE. $\frac{1}{4}$ sec. 19.....	Lignite.....	<i>Ft. in.</i>
554.....	NE. $\frac{1}{4}$ sec. 14.....	Bone.....	8 2
			2 8



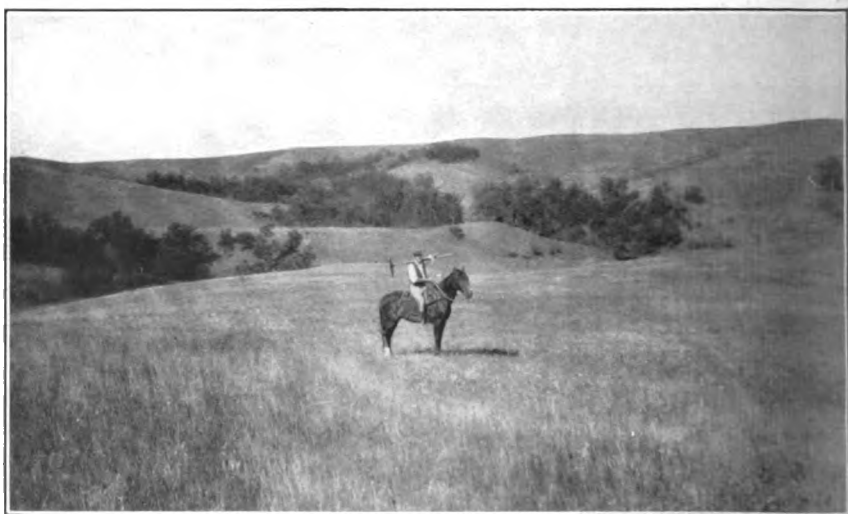
**A. FOSSIL LOG STANDING NEARLY UPRIGHT IN CLAY SHALE OF THE
FORT UNION FORMATION.**



B. FOSSIL STUMP IN FORT UNION FORMATION.



A. SAGE-BRUSH FLAT OF HANS CREEK, N. DAK., AND BLUFFS OF THE FORT UNION FORMATION.



B. ROLLING UPLAND IN THE FORT BERTHOLD INDIAN RESERVATION, N. DAK.

Sections 555 and 574, representing bed KK, were measured in T. 147 N., R. 93 W. (See Pl. XXIII.) A section of this bed in T. 147 N., R. 92 W., is given below.

Section of lignite bed KK at location 567, in sec. 19, T. 147 N., R. 92 W.

Sandstone.	Ft.	in.
Lignite		8
Shale, carbonaceous	3	
Lignite	1	6
Shale.		
	5	2

Sections 556, 575, and 593 represent lignite bed MM in T. 147 N., R. 93 W. The bed averages over 5 feet in thickness and is the highest bed of lignite that is exposed in this township. In many places its outcrop is obscured by clinker. In secs. 11, 14, 15, 16, 17, and 20, T. 147 N., R. 93 W., there are several large areas in which this bed has been burned.

In secs. 2, 5, and 34, T. 147 N., R. 93 W., excellent exposures of the rocks, chiefly above the horizon of bed MM, reveal only thin beds of lignite or none at all.

T. 147 N., R. 94 W.

The part of T. 147 N., R. 94 W., here described lies north of Little Missouri River. The lignite-bearing rocks are well exposed along that stream and its tributary gullies. The ground in the northern part of the township is level and covered by a thin mantle of glacial débris. A few foreign boulders derived from glacial drift are also found in the stream valleys, mingled with the alluvium of the river flood plain. A northwestward dip of 15 feet to the mile was noted in sec. 15, but elsewhere the beds have a general southeastward dip. Several high buttes occur in sec. 2.

Five beds of lignite crop out in this township. Bed EE, the lowest one, is represented by sections 604, 609, 613, and 614 (Pl. XXIII) and ranges in thickness from 7 feet 11 inches at location 604 to 10 feet 3 inches at location 614.

A lenticular bed near the horizon of bed FF and about 25 feet higher than bed EE has the following section at location 603:

Section of lignite bed at location 603, sec. 13, T. 147 N., R. 94 W.

Shale, sandy.	Ft.	in.
Lignite		8
Shale, carbonaceous	1	
Lignite		10
Shale, carbonaceous.		
	2	6

Sections 602, 605, 610, 617, and 618, Plate XXIII, represent bed GG, which ranges in thickness from 1 foot 2 inches at location

622 to 4 feet 2 inches at location 618. At location 617 the bed carries 2 feet 7 inches of lignite, containing a large amount of gypsum. At location 622 bed GG contains 1 foot 2 inches of lignite.

Bed HH was mapped in the western part of the township and is represented by sections 619, 620, and 622, Plate XXIII. Beds GG and HH are separated by about 20 feet of yellow sandstone, and it is notable that where one is thin the other is thick. Both beds are lenticular, and the lignite is variable in quality.

In the western part of this township beds II and JJ are mapped as one because they are generally separated by not more than 5 feet of strata, but in the eastern part (sec. 13, locations 600 and 601) these beds are separated by about 40 feet of shale and are mapped separately. This divergence of strata is not an uncommon feature in this field among thin beds of shale and sandstone as well as beds of lignite. (See fig. 15, p. 126.) Sections 601, 606, and 611 represent bed II; sections 600, 607, and 612 bed JJ; and sections 615, 616, 621, 623, and 624 the combined beds I-J.

Bed KK is less than 2 feet thick in this township and was not mapped. The highest bed mapped is bed MM, which, as measured at location 608, is 3 feet 9 inches thick. (See Pl. XXIII.)

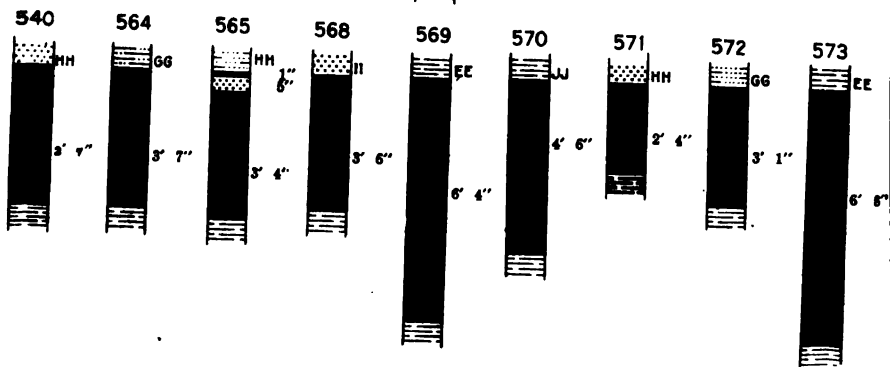
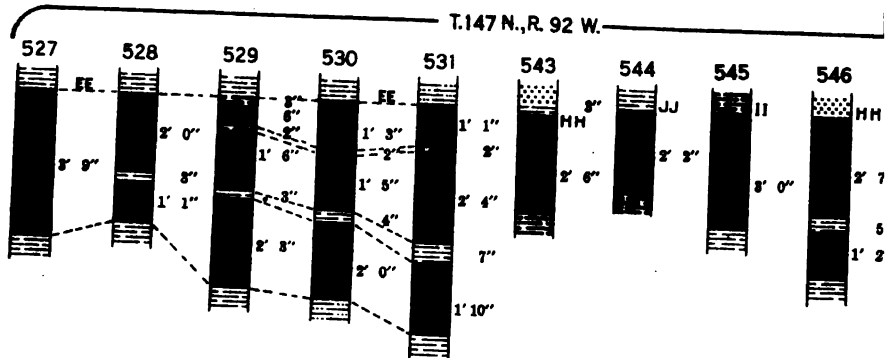
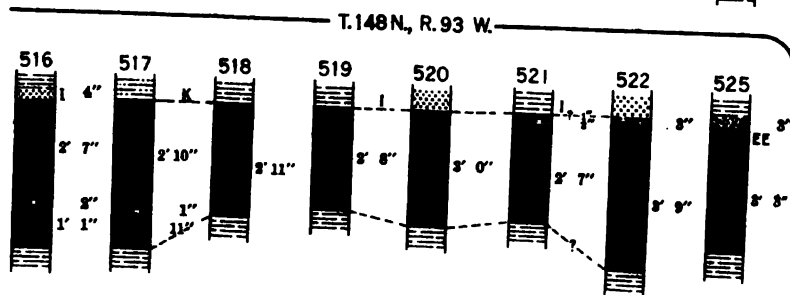
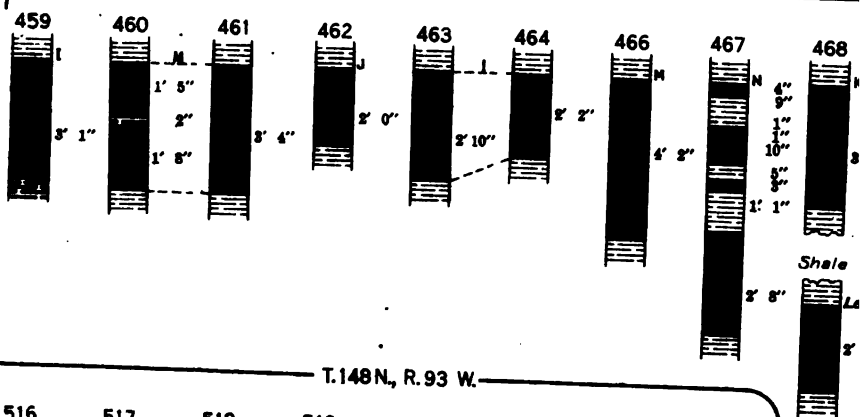
T. 147 N., R. 95 W.

The part of T. 147 N., R. 95 W., here described lies north of Little Missouri River. Rocks are exposed in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 1, but elsewhere the surface material is the alluvium of the river flood plain. One bed of lignite was found and as measured at location 625 (see Pl. XXIII) has a thickness of 4 feet 10 inches. This bed is believed to be bed EE, mapped in T. 147 N., R. 93 W. The strata have a slight eastward dip.

T. 147 N., R. 92 W., EAST OF LITTLE MISSOURI RIVER.

The part of T. 147 N., R. 92 W., which lies west of Little Missouri River is described on pages 151-153, in connection with T. 147 N., R. 93 W.; the part here described lies east of Little Missouri River. This stream has a deep troughlike valley, on either side of which, in a belt 3 or 4 miles wide, are the extensive badlands shown in Plate XIV. These consist of small gorges or steep-sided gulches cut into the uplands so as to form an intricate network of drainage and make the tract practically impassable. In many places these gullies are only a few feet in width, but their depth may be so great as to make it impossible to cross them. The upland is rolling and well covered with grass. The rocks exposed in the township consist principally of sandy shale and sandstone, with numerous beds of lignite. Some of the strata are cross-bedded and exhibit other features indicative of

U. S. GEOLOGICAL SURVEY



deposition by rapidly moving currents of water; some suggest eolian deposition; others suggest deposition in swirls or eddies of streams; still others appear to have been formed in deltas; and undoubtedly some of the beds of carbonaceous shale and lignite were formed in marshes. The strata lie nearly flat, as is proved by the fact that altitudes on the same bed of lignite 5 or 6 miles apart are, as a rule, nearly the same. However, local dips in various directions were noted. The maximum relief in this township is about 600 feet.

Nine beds of lignite 2 feet or more in thickness have been traced and mapped in this township, some for only short distances and others across the entire township. The approximate stratigraphic positions of these beds are shown in section 7, Plate XVI. At many of the locations two or more lignite beds are exposed, and in the following descriptions the numbers are repeated for each bed. The lowest bed exposed is bed DD, which was mapped for a short distance in secs. 1 and 12 and measured at locations 749 and 750. At location 749 it contains 2 feet 4 inches of lignite, and at location 750 it contains 1 foot 7 inches.

Bed EE is about 30 feet higher than bed DD and is probably the most valuable bed in this township and the one immediately to the west, as it averages over 4 feet in thickness and underlies practically all of the area except the flood plain of Little Missouri River. It was measured at locations 641, 715, 726, 729, 730, 732, 733, 739, 740, 745, 746, 748, 749, and 751. Sections at all these locations are shown on Plate XXVI, except Nos. 748 and 749, which are given below.

Sections of lignite bed EE in T. 147 N., R. 92 W.

[In addition to those shown on Plate XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
748.....	NE. $\frac{1}{4}$ sec. 13.....	Shale.....	Fl. in.
		Shale, carbonaceous.....	3
		Lignite.....	1
		Shale, carbonaceous.....	1
		Lignite, dirty.....	8
749.....	NE. $\frac{1}{4}$ sec. 12.....	Shale.....	
		Shale, carbonaceous.....	1 2
		Lignite.....	1 8
		Shale.....	

Bed FF is about 20 feet above bed EE and is very lenticular. It was mapped only in the northern part of this township and was measured at locations 730, 732, 733, and 739 (Pl. XXVI). The bed contains 1 foot 9 inches of lignite at location 730 and 1 foot 8 inches at location 739.

Bed GG is about 30 feet above bed FF and averages more than 3 feet in thickness in the eastern part of the township, but in the western part it is very thin or absent. Sections 729, 730, 739, 742,

746, and 747 were measured on bed GG; section 746 is shown on Plate XXVI, and the other measurements are given in the following table:

Sections of lignite bed GG in T. 147 N., R. 92 W.

[In addition to that shown on Plate XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	Pl. in.
729.....	SW. $\frac{1}{4}$ sec. 4.....	Sandstone.....	
		Lignite.....	10
		Shale.....	8
		Lignite, poor.....	1 2
		Shale.....	
730.....	NW. $\frac{1}{4}$ sec. 3.....	Shale.....	
		Lignite.....	6
		Shale.....	5
		Lignite, dirty.....	1 2
		Shale.....	
739.....	NW. $\frac{1}{4}$ sec. 13.....	Shale.....	
		Lignite.....	5
		Shale.....	2
		Lignite.....	1 3
		Shale.....	
742.....	SW. $\frac{1}{4}$ sec. 13.....	Lignite.....	8
		Shale, carbonaceous.....	4
		Lignite.....	1 8
747.....	NE. $\frac{1}{4}$ sec. 13.....	Shale.....	
		Lignite.....	1 7
		Shale, sandy.....	

A lenticular bed at about the horizon of bed GG was measured at location 718, where it contains but 1 foot 2 inches of lignite. Bed HH is separated from bed GG by about 25 feet of drab shale, and it has an average thickness of 2 feet 8 inches. In this township the bed was measured at locations 637, 638, 642, 714, 716, 719, 726, 727, 729, and 745.¹² These sections are shown on Plate XXVI, with the exception of those given below.

Sections of lignite bed HH in T. 147 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	Pl. in.
716.....	SE. $\frac{1}{4}$ sec. 29.....	Lignite.....	2
719.....	SW. $\frac{1}{4}$ sec. 20.....	Shale.....	
		Bone.....	4
		Shale.....	3
		Lignite.....	1 4
		Shale.....	
727.....	SE. $\frac{1}{4}$ sec. 16.....	Sandstone.....	
		Lignite.....	3
		Shale.....	3
		Lignite.....	1 8
		Shale.....	
729.....	SW. $\frac{1}{4}$ sec. 4.....	Lignite.....	3
745.....	NW. $\frac{1}{4}$ sec. 24.....	Lignite.....	2

¹² Section 745 is labeled bed GG on Plate XXVI; it should be labeled bed HH.

The next important bed of lignite higher in the section is bed II, which averages 3 feet in thickness and was measured at locations 639, 642, 700, 710, 712, 714, 716, 720, 726, 727, 728, 729, 731, 735, 736, 737, 738, 741, 742, 743, and 746. These sections are given graphically on Plate XXVI with the exception of those tabulated below.

Sections of lignite bed II in T. 147 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
712.....	NE. $\frac{1}{2}$ sec. 34.....	Sandstone.....	<i>Ft. in.</i>
		Lignite.....	3 4
		Shale.....	
716.....	SE. $\frac{1}{2}$ sec. 29.....	Lignite.....	3
729.....	SW. $\frac{1}{2}$ sec. 4.....	Lignite.....	1 8
737.....	SE. $\frac{1}{2}$ sec. 16.....	Lignite.....	2
742.....	SE. $\frac{1}{2}$ sec. 13.....	Lignite.....	2
746.....	SE. $\frac{1}{2}$ sec. 13.....	Shale.....	
		Lignite.....	1
		Shale, carbonaceous.....	11
		Shale.....	

Bed JJ, whose average thickness is 1 foot 8 inches, was measured at locations 716, 721, 726 to 729, 731, 735 to 738, 741 to 743, and 745. These measurements are shown graphically on Plate XXVI, with the exception of those tabulated below.

Sections of lignite bed JJ in T. 147 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
716.....	SE. $\frac{1}{2}$ sec. 29.....	Lignite.....	2
721.....	SE. $\frac{1}{2}$ sec. 20.....	Lignite.....	2 2
727.....	SE. $\frac{1}{2}$ sec. 16.....	Lignite.....	1 10
728.....	NE. $\frac{1}{2}$ sec. 16.....	Lignite.....	1 8
729.....	SW. $\frac{1}{2}$ sec. 4.....	Lignite.....	1 7
731.....	SE. $\frac{1}{2}$ sec. 3.....	Lignite.....	1 2
735.....	SE. $\frac{1}{2}$ sec. 11.....	Lignite.....	1
736.....	SE. $\frac{1}{2}$ sec. 11.....	Lignite.....	1 5
737.....	SE. $\frac{1}{2}$ sec. 15.....	Lignite.....	1 1
738.....	SW. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 3
741.....	NE. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 6
742.....	SE. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 2
743.....	SE. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 2

Bed KK, which averages $2\frac{1}{2}$ feet in thickness in this township, was measured at locations 640, 701, 704, 706, 708, 709, 713, 716, 717, 722, 726 to 728, 731, 734 to 738, and 741 to 743. The measurements of this bed are shown graphically on Plate XXVI, with the exception of those tabulated on page 158.

Sections of lignite bed KK in T. 147 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
701.....	SW. $\frac{1}{2}$ sec. 35.....	Lignite.....	1 2
704.....	NW. $\frac{1}{2}$ sec. 35.....	Lignite.....	1 8
706.....	SW. $\frac{1}{2}$ sec. 26.....	Lignite.....	1 10
708.....	SW. $\frac{1}{2}$ sec. 26.....	Lignite.....	1 10
709.....	SE. $\frac{1}{2}$ sec. 27.....	Lignite.....	2 4
716.....	SE. $\frac{1}{2}$ sec. 29.....	Lignite.....	2 2
736.....	SE. $\frac{1}{2}$ sec. 11.....	Lignite.....	1 5
738.....	SW. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 10
741.....	NW. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 5
742.....	SE. $\frac{1}{2}$ sec. 14.....	Lignite.....	1 1
743.....	SE. $\frac{1}{2}$ sec. 14.....	Lignite (bottom of bed unexposed).....	1 6+

Bed LL is generally less than 2 feet thick in this township and contains lignite of poor quality. It is represented by sections 702, 708, 713, 716, 723, 728, 737, and 745. Sections 713 and 745 are shown graphically on Plate XXVI; the remainder are tabulated below.

Sections of lignite bed LL in T. 147 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
702.....	SW. $\frac{1}{2}$ sec. 35.....	Lignite.....	1 10
708.....	SW. $\frac{1}{2}$ sec. 26.....	Lignite.....	8
716.....	SE. $\frac{1}{2}$ sec. 29.....	Lignite.....	3
723.....	SE. $\frac{1}{2}$ sec. 20.....	Lignite.....	1 11
728.....	NE. $\frac{1}{2}$ sec. 16.....	Lignite, very impure.....	2
737.....	SE. $\frac{1}{2}$ sec. 15.....	Lignite, impure.....	2 11

Bed MM is the highest bed of lignite mapped in the township, and it averages 3 feet in thickness, as shown by sections 689, 705, 708, 711, 713, 716, 724, and 725. All these sections are given on Plate XXVI except section 716, which shows 1 foot of lignite.

Several thin lenses of lignite from 10 to 15 feet above bed MM were measured at locations 688, 707, 713, and 728. These measurements are tabulated below.

Sections of lignite lenses above bed MM in T. 147 N., R. 92 W.

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
688.....	SW. $\frac{1}{2}$ sec. 36.....	Lignite, dirty.....	1 4
707.....	SW. $\frac{1}{2}$ sec. 26.....	Lignite.....	9
713.....	NW. $\frac{1}{2}$ sec. 34.....	Lignite.....	1 2
728.....	NE. $\frac{1}{2}$ sec. 16.....	Lignite.....	1 10

T. 146 N., R. 92 W.

The part of T. 146 N., R. 92 W., here described lies within the Fort Berthold Reservation. Hans Creek flows northwestward through the township, entering at sec. 12 and leaving at sec. 4. Its valley, as shown in Plate XXII, A, is fairly wide for the size of the stream and is bordered on either side by badlands, particularly in the northwestern part of the township. Many of the tributary streams are cut into the soft Fort Union strata, so that gorges and canyons are common. Fantastic peaks of Fort Union strata, such as the one shown in Plate XVIII, A, overlook the valley from the south, and the wash of the rain has carved them into fantastic shapes and seamed them with countless channels of the most delicate tracery. These precipitous peaks, together with the steep-sided canyons, make the country exceedingly difficult to cross. The relief amounts to about 400 feet in the maximum but is considerably less in the eastern part of the township than in the western part.

The lignite-bearing rocks are exposed in the bluffs on either side of Hans Creek and along its tributaries. Along the stream itself alluvium covers the stratified formation to a considerable depth. On the uplands a thin mantle of glacial drift is found in several localities, but usually the drift amounts to only a scattering of pebbles and boulders. It is doubtful if at any place in this township the drift is more than 15 feet thick. Consolidated glacial drift 12 feet thick was found in sec. 6 on a high ridge within half a mile of Little Missouri River. The drift does not, however, generally obscure the outcrops of lignite beds in this township.

The approximate vertical position of the lignite beds in this township is shown in stratigraphic section 7, Plate XVI. At several of the locations indicated by numbers on this section two or more beds of lignite occur. The lowest bed of lignite exposed in this township was measured at location 647, in sec. 5. This bed, as indicated by measurements in the surrounding townships, has an average thickness of over 5 feet and has been called for convenience bed EE and correlated with bed EE north of Little Missouri River. At location 647 the entire thickness could not be measured owing to the fact that the base of the bed was covered by a large slump. However, it carries over 6 feet of lignite at this place. (See Pl. XXVI.) The next higher important bed of lignite in this township is separated from bed EE by about 100 feet of sandy shale and sandstone containing two thin beds of lignite. These thin beds (FF and GG) were not mapped, as each contains less than 2 feet of good lignite. Bed HH, which has an average thickness of about 4 feet 6 inches in this township, was measured at locations 645, 646, 648, 649, 651, 654, 657, 658,

659, 666, 668, 670, 695, 697, and 699. All the sections are shown on Plate XXVI.

Bed II, which has an average thickness of about 2 feet 6 inches, was measured at locations 645, 646, 651, 652, 653, 656, 658, 660, 664, 665, 667, 671, 672, 685, 694, 696, and 699, as shown in Plate XXVI. Sections of bed II not shown on this plate are given in the following table:

Sections of lignite bed II in T. 146 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Pt. in.</i>
658.....	NE. $\frac{1}{4}$ sec. 9.....	Lignite.....	2 2
660.....	SE. $\frac{1}{4}$ sec. 9.....	Lignite.....	2 2
667.....	NE. $\frac{1}{4}$ sec. 10.....	Lignite.....	3

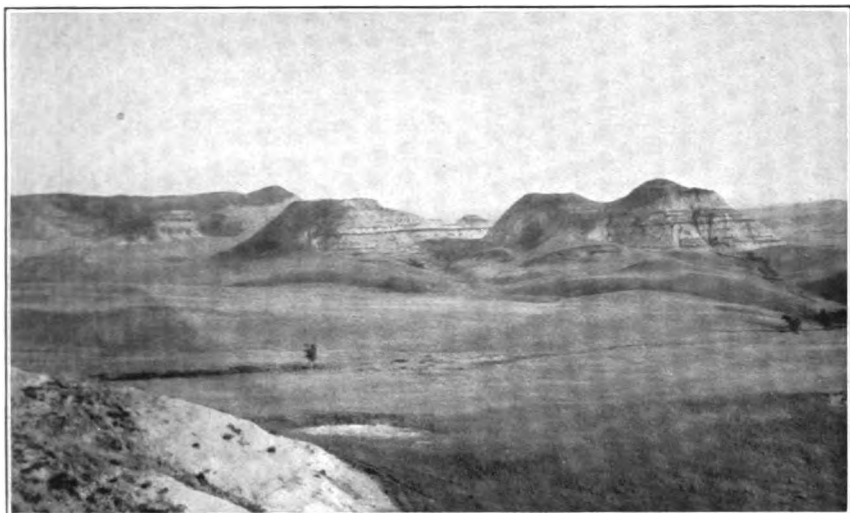
Bed JJ was measured at locations 645, 651, 655, 658, 661, 662, 669, 673, and 698. This bed averages less than 2 feet in thickness and is of poor quality. Section 661 is shown on Plate XXVI, and others are given in the following table:

Sections of lignite bed JJ in T. 146 N., R. 92 W.

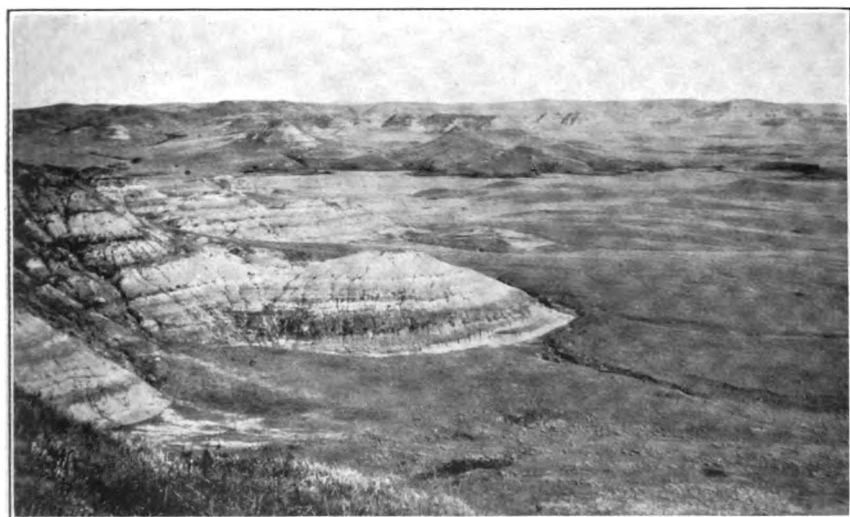
[In addition to that shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Pt. in.</i>
645.....	NW. $\frac{1}{4}$ sec. 5.....	Lignite.....	2 1
651.....	SW. $\frac{1}{4}$ sec. 8.....	Shale, carbonaceous.....	8
		Lignite.....	1 10
		Shale, carbonaceous.....	8
655.....	SE. $\frac{1}{4}$ sec. 8.....	Lignite.....	1 5
658.....	NE. $\frac{1}{4}$ sec. 9.....	Lignite.....	1 3
662.....	SW. $\frac{1}{4}$ sec. 9.....	Lignite.....	1 7
669.....	NE. $\frac{1}{4}$ sec. 11.....	Lignite.....	1 10
673.....	NE. $\frac{1}{4}$ sec. 13.....	Lignite.....	1 8
698.....	NE. $\frac{1}{4}$ sec. 3.....	Lignite.....	1 6

Bed KK is of value in the township to the north but is thin or absent throughout most of this township. It was measured, however, at locations 651, 655, 658, 661, 662, 682, 683, 686, 687, 690, and 692. All these sections are tabulated below, with the exception of sections 683 and 686, which are shown graphically on Plate XXVI.



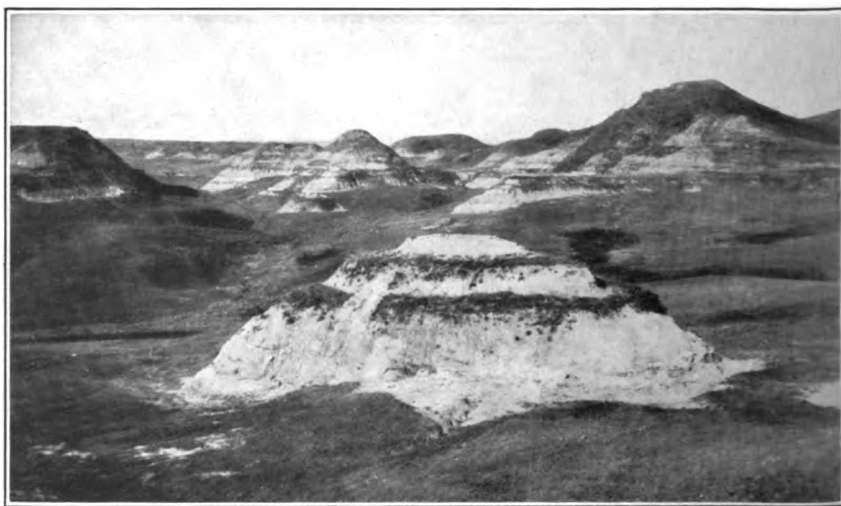
A. BUTTES IN SEC. 9, T. 148 N., R. 93 W., N. DAK.



B. BUTTES IN T. 148 N., R. 93 W., N. DAK.



A. VIEW UP SQUAW CREEK, N. DAK.



**B. BARE BUTTES IN SQUAW CREEK VALLEY IN SEC. 10, T. 148 N., R. 93 W.,
N. DAK.**

Sections of lignite bed KK in T. 146 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
651.....	SW. $\frac{1}{2}$ sec. 8.....	Lignite.....	<i>Pt. in.</i>
656.....	SE. $\frac{1}{2}$ sec. 8.....	Lignite.....	1 8
658.....	NE. $\frac{1}{2}$ sec. 9.....	Lignite.....	1 6
661.....	SW. $\frac{1}{2}$ sec. 9.....	Lignite.....	1 10
662.....	SW. $\frac{1}{2}$ sec. 9.....	Lignite.....	1 6
662.....	NE. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 7
667.....	NW. $\frac{1}{2}$ sec. 1.....	Lignite.....	2 3
690.....	NE. $\frac{1}{2}$ sec. 2.....	Lignite.....	2 2
692.....	NE. $\frac{1}{2}$ sec. 2.....	Lignite.....	1 1

A carbonaceous shale bed about 20 feet thick and about 15 feet above bed KK was noted at location 691, where it pinches out southward, being replaced by a bed of buff sandstone 20 feet thick. Half a mile to the north this carbonaceous bed suddenly becomes thin, and at location 693 it is replaced by a coarse buff sandstone, which is cross-bedded.

Bed LL lies in a zone of carbonaceous shale and is generally thin and shaly. Measurements of it were obtained at locations 643, 651, 658, 661, 663, and 681. These measurements are tabulated below or shown graphically on Plate XXVI.

Sections of lignite bed LL in T. 146 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
643.....	NW. $\frac{1}{2}$ sec. 6.....	Lignite.....	<i>Pt. in.</i>
651.....	SW. $\frac{1}{2}$ sec. 8.....	Lignite.....	1 8
663.....	NW. $\frac{1}{2}$ sec. 16.....	Lignite.....	1 8
681.....	NE. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 11
		Lignite.....	11

The highest bed of lignite in this township is bed MM. It is about 300 feet above bed EE and ranges in thickness from about 1 foot 1 inch at location 650 to 6 feet 4 inches at location 661, having an average thickness of about 3 feet of good lignite. Sections were measured at locations 644, 650, 651, 658, 661, 680, and 684 and are shown on Plate XXVI or tabulated below.

Sections of lignite bed MM in T. 146 N., R. 92 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
650.....	NW. $\frac{1}{2}$ sec. 17.....	Lignite.....	<i>Pt. in.</i>
651.....	SW. $\frac{1}{2}$ sec. 8.....	Shale, carbonaceous.....	1 1
		Lignite.....	5
		Shale.....	2 4
680.....	NE. $\frac{1}{2}$ sec. 12.....	Lignite.....	1 6

So far as known there are in this immediate locality no beds of lignite of any importance higher than bed MM, nor any lower than bed EE. The nearest location on a bed greater than 3 feet in thickness and stratigraphically below bed EE is in sec. 9, T. 147 N., R. 90 E., where bed CC has a reported thickness of 6 feet. As bed CC dips beneath the surface of Missouri River at this place it is probable that the bed underlies all of this township, with an average thickness of more than 3 feet.

T. 148 N., R. 91 W., SOUTH OF LITTLE MISSOURI RIVER.

The part of T. 148 N., R. 91 W., that is described here lies south of Little Missouri River and west of Missouri River. The surface of this part of the township is made up of the flood plains of the main rivers and a strip of badlands along the south. The maximum relief is about 200 feet.

The rocks consist mainly of sandy shale and sandstone interbedded with carbonaceous shale and thin beds of lignite. The surface material is largely alluvium. In places a few boulders of crystalline rock weighing several tons each were noted, which indicate that this area has been subjected to glaciation.

Altitudes of certain beds of lignite at different places indicate that the dip of the strata is very slight or practically horizontal. Two beds of lignite are mapped in this township. Bed EE is the lower one, and was measured at locations 758, 759, 760, and 761. At location 758 it contains 2 feet 2 inches of lignite; at location 761, 11 inches of lignite overlain by 8 inches of bone; and at location 759, 2 feet 7 inches of lignite. Sections 759 and 760 appear on Plate XXVI. Bed GG was mapped in sec. 34 of this township. Sections on this bed were obtained in sec. 3 of the township immediately to the south. As both of these beds of lignite average less than 2 feet in thickness they are not considered valuable. However, it is believed that the township is underlain by thicker beds of lignite at a depth of less than 300 feet.

T. 147 N., R. 91 W.

All of T. 147 N., R. 91 W., is described here except part of sec. 1, which lies northeast of Missouri River.

In the northern part of this township steep-sided gullies and ravines cut into the upland to a depth of about 300 feet. The maximum relief in the township, however, amounts to about 500 feet. South of the central part is a high rolling upland surmounted in places by grass-covered mounds 50 or 60 feet higher than the main level. Along Missouri River in secs. 1 and 12 are steep bluffs caused by the undercutting of the stream. Many landslides occur on these bluffs; the largest seen, in sec. 1, is about half a mile in length and

800 to 1,000 feet in width. The vertical displacement due to the slide is about 300 feet. Part of the material has slid into Missouri River and is gradually being carried away by the stream. Another slide, which is probably older than the one just mentioned, extends for about half a mile along the river bluff in the NE. $\frac{1}{4}$ sec. 12 and into sec. 1 of this township and sec. 7 of the township to the east. The strata in every slide in this locality dip from 1° or 2° to 40° toward the bluff from which the material is derived.

The rocks in this township are composed of sandy shale and sandstone interbedded with thin layers of carbonaceous shale and lignite. The strata lie nearly flat; a northwestward dip of perhaps as much as 8 feet to the mile has been noted in secs. 3 and 10. A few glacial boulders are scattered on the upland, but in the rough country near Missouri River and in the northern part of this township practically all the drift has been removed by stream erosion.

The lignite beds in the township are much thinner than those of adjoining townships. The number of mappable beds is four, whereas in the township immediately to the west there are nine. The lowest bed of lignite mapped in this township is bed DD. Only one measurement of this bed was obtained—at location 780, in sec. 12, where it contains 1 foot 1 inch of lignite.

The next higher bed is EE, on which measurements were made at locations 764, 769, and 777.

Sections of lignite bed EE in T. 147 N., R. 91 W.

[In addition to that shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
764.....	NW. $\frac{1}{4}$ sec. 4.....	Shale.....	<i>Ft. in.</i>
		Lignite.....	6
		Shale.....	8
		Shale, carbonaceous.....	2
		Lignite.....	10
		Shale, carbonaceous.....	10
		Lignite.....	4
		Shale, carbonaceous.....	8
777.....	NW. $\frac{1}{4}$ sec. 12.....	Lignite.....	1 7

At location 769 only 3 feet of lignite is exposed, the lower part of the bed being concealed by water. The section is shown on Plate XXVI. Bed EE becomes thinner to the north and is less than 2 feet in thickness near the township line. South and west of this township this bed is much thicker; in the township immediately to the west it has an average thickness of over 4 feet; and in T. 147 N., R. 94 W., it has a maximum observed thickness of 14 feet. It is probable that bed CC lies at a depth of less than 500 feet beneath this township and carries more than 2 feet of lignite. A bed about

20 feet above bed EE and 3 feet thick was measured at locations 755, 778, 779, and 780. Section 755 is shown on Plate XXVI. Other sections of bed FF are tabulated below:

Sections of lignite bed FF in T. 147 N., R. 91 W.

[In addition to that shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
778.....	SW. $\frac{1}{4}$ sec. 1.....	Shale, carbonaceous.....	10
		Lignite.....	11
		Shale.....	5
		Lignite.....	1
		Shale.....	
779.....	NE. $\frac{1}{4}$ sec. 12.....	Shale.....	
		Lignite.....	1 7
		Shale, carbonaceous.....	8
		Lignite.....	6
		Shale.....	3
		Lignite, dirty.....	6
		Shale.....	
780.....	SE. $\frac{1}{4}$ sec. 12.....	Shale.....	
		Shale, carbonaceous.....	10
		Lignite.....	1 4
		Shale, carbonaceous.....	1
		Shale.....	

Bed GG, which has an average thickness in this township of 2 feet 6 inches, is separated from bed FF by about 30 feet of sandy shale and crops out in secs. 3, 4, 5, 9, and 10. Measurements of this bed were obtained at locations 762, 763, 765 to 768, 770, 772, 773, and 775. (See Pl. XXVI.)

Sections of lignite bed GG in T. 147 N., R. 91 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
			<i>Ft. in.</i>
762.....	NE. $\frac{1}{4}$ sec. 5.....	Lignite.....	1 10
767.....	SW. $\frac{1}{4}$ sec. 3.....	Shale, sandy.....	
		Shale, carbonaceous.....	6
		Lignite.....	1 8
		Shale, carbonaceous.....	7
		Lignite.....	5
		Shale.....	
768.....	NE. $\frac{1}{4}$ sec. 3.....	Shale.....	
		Shale, carbonaceous.....	5
		Lignite.....	1
		Shale, carbonaceous.....	2
		Lignite.....	7
770.....	NE. $\frac{1}{4}$ sec. 10.....	Lignite.....	2 6
772.....	NE. $\frac{1}{4}$ sec. 10.....	Shale.....	
		Lignite.....	1 5
		Shale, carbonaceous.....	1 1
		Lignite.....	3
		Shale.....	

West of location 762 bed GG is less than 2 feet thick and was not mapped for several miles.

Bed HH is of mappable thickness in sec. 17. It is 2 feet 5 inches thick at location 754 (Pl. XXVI) and 1 foot 3 inches at location 771. Thin beds of lignite higher in the section were measured in secs. 7, 18, and 19. Bed II was measured at location 757, in the SW. $\frac{1}{4}$ sec. 7, where it carries 1 foot 10 inches of lignite.

The thickness of bed JJ was obtained at locations 752, 753, and 774.

Sections of lignite bed JJ in T. 147 N., R. 91 W.

No. on map (Pl. XXIX).	Location.	Section.	
752.....	SW. $\frac{1}{4}$ sec. 19.....	Lignite.....	<i>Ft. in.</i> 2 1
753.....	NW. $\frac{1}{4}$ sec. 19.....	Lignite.....	1 7
774.....	SE. $\frac{1}{4}$ sec. 10.....	Shale. Shale, carbonaceous. Lignite..... Shale.	 1 3

Other sections of thin beds which may be the same as higher beds already described were obtained at locations 678 and 776. At location 678 a bed carrying 1 foot 11 inches of lignite was measured, and at location 776 a section 1 foot 3 inches thick was obtained.

T. 146 N., R. 91 W.

That part of T. 146 N., R. 91 W., which lies within the Fort Berthold Reservation has a fairly regular surface, though in the western part the relief amounts to several hundred feet. In the central and eastern parts the surface is rolling and generally grass covered. Although the ground is commonly covered with glacial drift it does not affect the surface features noticeably. The rocks are composed of light-yellow sandstone and gray shale interbedded with lignite. The lignite is thin and usually of poor quality. The township is probably underlain by a bed of lignite which crops out on Hans Creek in T. 146 N., R. 92 W., and was measured at locations 668 and 695. This bed (HH) averages over 4 feet in thickness on Hans Creek. Another still lower bed that may underlie this township is bed EE, which averages about 5 feet in thickness on Hans Creek and Little Missouri River in Tps. 146 and 147 N., R. 92 W. Beds II, KK, and MM are mapped for short distances in secs. 6, 7, and 18 of this township. All these beds, however, are less than 2 feet 6 inches thick. Measurements of them are given in the following table:

Sections of lignite beds II and KK in T. 146 N., R. 91 W.

No. on map (Pl. XXIX).	Location.	Bed.	Section.	Ft. in.
674.....	NW. $\frac{1}{4}$ sec. 18.....	II.....	Lignite (thickness reported)	3 $\frac{1}{2}$
675.....	NW. $\frac{1}{4}$ sec. 7.....	II.....	Lignite.....	1 10
676.....	NE. $\frac{1}{4}$ sec. 7.....	II.....	Lignite.....	1 8
677.....	SW. $\frac{1}{4}$ sec. 6.....	KK.....	Lignite.....	1 10
679.....	NE. $\frac{1}{4}$ sec. 6.....	KK.....	Lignite.....	1 9

Bed MM was not measured in this township but was mapped a short distance on the strength of a measurement made at location 680, in the township immediately to the west, where it is only 1 foot 6 inches thick.

T. 147 N., R. 90 W.

That part of T. 147 N., R. 90 W., here described lies south of Missouri River. The principal surface features are Missouri River and its bluffs. The river flows through secs. 7, 8, 9, 10, and 11 and for the greater part of the way is undercutting the bluffs on its south bank, which in many places are 250 to 300 feet high, forming sheer walls of sedimentary rocks. In other places landslides have caused thousands of tons of material to slide into the river. One of the most notable of these slides is mapped in the SW. $\frac{1}{4}$ sec. 8. A large creek flowing through the southeastern part of this township, leaving it in sec. 24, has a wide valley well covered with grass and is peculiar because of the large number of seeps and springs it contains. At many places along this stream there are pools 10 or 12 feet deep. The general covering of glacial drift in the southern part of this township is not thick enough to affect the form of the surface.

The rocks exposed in the sections on Missouri River consist of sandy shale and sandstone, together with thin beds of carbonaceous shale and lignite. There is probably about 200 feet of the Fort Union formation beneath the lowest beds exposed in this township.

The lowest bed of lignite that crops out in the township is bed CC, which was measured at locations 788, 806, and 809. At location 788 4 feet of lignite was measured above the water of Missouri River in September, 1912. Owing to the height of the water a complete section could not be measured. It was reported, however, that the lignite bed at this place is more than 6 feet thick and is mined during the winter when the water is low and the river frozen. This measurement is believed to be on bed CC, which was mapped for 15 miles in the township immediately to the east. Sections 806 and 809 are shown on Plate XXVI. The next higher bed of lignite is bed DD, which averages 2 feet 8 inches in thickness and was measured at locations 796, 797, 804, 805, 807, 808, and 813. At locations 796 and 797 bed DD carries 1 foot 9 inches of lignite. Other measurements of

this bed are shown on Plate XXVI. Its quality as well as its thickness is variable. Bed EE has an average thickness of 2 feet 4 inches and is separated in this township from bed DD by about 35 feet of shale. It was measured at locations 781, 782, 784, 785, 787, 791 to 795, 799, 803, 810, 814, and 815. These sections, with the exception of those tabulated below, are shown on Plate XXVI.

Sections of lignite bed EE in T. 147 N., R. 90 W.

[In addition to those shown on Plate XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	Ft. in.
787.....	SE. $\frac{1}{4}$ sec. 8.....	Lignite.....	1 11
793.....	SW. $\frac{1}{4}$ sec. 10.....	Lignite.....	2 1
810.....	SE. $\frac{1}{4}$ sec. 27.....	Lignite, impure.....	1 6
814.....	NE. $\frac{1}{4}$ sec. 25.....	Shale.....	
		Lignite.....	1
		Shale.....	3
		Lignite.....	6
		Shale.....	
815.....	NE. $\frac{1}{4}$ sec. 25.....	Lignite.....	1 4

Bed FF, which has an average thickness of 2 feet 11 inches, is separated from bed EE by 5 to 20 feet of shale. It seems probable that this bed is the upper part of bed EE of the township immediately to the east and that in this township it becomes separated from that bed by the increasing thickness of the shale parting. Bed FF was measured at locations 783, 786,¹³ 789, 790, 798, 800, 801, and 802. (See Pl. XXVI.) A section measured at location 811, in sec. 19, may represent bed FF, although the correlation is uncertain. At this place a spring issues from an outcrop of lignite, and an incomplete section shows 4 feet 2 inches of lignite of good quality. In secs. 24, 25, and 36 a lens of lignite lies between bed DD and bed EE. It was measured at locations 813 and 815 and apparently becomes thicker toward the south. The lens is only 8 inches thick at location 815 and continues to thin northward from this point. Several beds of lignite higher in the geologic section were noted but are too thin to be of any value.

T. 146 N., R. 90 W.

The part of T. 146 N., R. 90 W., that lies within the Fort Berthold Reservation has very little relief. The streams flow in broad valleys that are partly filled with glacial drift. However, the glacial drift is so old that the surface is not materially modified by it.

¹³ The two sections on Plate XXVI labeled 783 should be 783 and 786.

The rocks underlying the glacial drift carry lignite, although no exposed lignite beds were found within the township, and the strata that crop out are beds which for this field are high in the Fort Union formation. It is probable, therefore, that the township is underlain by the lignite beds that crop out in townships to the east, north, and west.

T. 147 N., R. 89 W.

That portion of T. 147 N., R. 89 W., that lies south of Missouri River includes in its northern half the flood plain of the river, which in places is several miles wide. A bluff that has an average height of about 40 feet and in the eastern and western parts is apparently a river-built terrace extends across secs. 18, 20, 21, 25, 26, and 27. In the central part the bluff is cut by gullies into badlands. In secs. 27, 28, 29, and 30 badlands are present. Above this terrace is a high grass-covered upland extending across the southern part of the township. The relief reaches a maximum of about 450 feet. The flood plain of Missouri River is well covered with underbrush and trees, whereas the badlands are only sparsely covered with grass and in many places are totally bare. On the upland grass is abundant.

The strata have a southwestward dip of less than 10 feet to the mile. Exposures of the rocks are few, owing to the fact that on the river flood plain they are buried many feet beneath alluvium, and on the upland they are covered with glacial drift. The drift, however, is thin and in many places consists of only a few boulders scattered on the surface. A mass of drift which has been baked by the burning of a lignite bed caps a ridge in the NW. $\frac{1}{4}$ sec. 28, at location 826.

The lowest bed of lignite that crops out in this township was found in the SE. $\frac{1}{4}$ sec. 21, at location 827. This bed, which is at about the same horizon as bed BB, contains 3 feet 5 inches of lignite. This is the only measurement on bed BB in this locality, but a bed at about the same horizon was mapped for considerable distances in T. 150 N., R. 94 W., along Bear Den Creek. Bed CC was measured at locations 818, 825, 829, and 839. At location 818, where the lignite is mined by stripping, the bed is 6 feet 10 inches thick, and although it contains some poor lignite it is probably the best source of lignite for local use. Other measurements of bed CC, which are given on Plate XXVI, show its average thickness to be 6 feet. The next higher bed of lignite, bed DD, which has an average thickness of 2 feet, was measured at locations 816, 819, 822, and 823. Section 822 is shown graphically on Plate XXVI. Other sections of bed DD are given in the following table:

Sections of lignite bed DD in T. 147 N., R. 89 W.

[In addition to that shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
816.....	SW. $\frac{1}{4}$ sec. 19.....	Lignite.....	<i>Ft. in.</i> 1 8
819.....	SW. $\frac{1}{4}$ sec. 20.....	Lignite.....	10
823.....	SW. $\frac{1}{4}$ sec. 28.....	Sandstone.....	
		Lignite.....	1 2
		Shale.....	8
		Lignite.....	2
		Shale.....	1
		Lignite.....	6
		Shale.....	

A lens of lignite mapped for a short distance in this township and the one immediately to the west lies about 25 feet above bed DD and was measured at location 812. Here it contains 4 feet 8 inches of lignite, but both east and west of this place it pinches out rapidly.

The next higher valuable bed of lignite in this township is bed EE, measurements of which were obtained at locations 817, 820, 821, 823, 824, 828, and 830.¹⁴ (See Pl. XXVI.) Bed EE is the highest bed of lignite exposed and has an average thickness of about $3\frac{1}{2}$ feet in this township.

Sections of lignite bed EE in T. 147 N., R. 89 W.

[In addition to those shown on Pl. XXVI.]

No. on map (Pl. XXIX).	Location.	Section.	
817.....	SW. $\frac{1}{4}$ sec. 19.....	Lignite.....	<i>Ft. in.</i> 2
823.....	SW. $\frac{1}{4}$ sec. 28.....	Lignite.....	3 2

T. 146 N., R. 89 W.

The part of T. 146 N., R. 89 W., which lies within the Fort Berthold Reservation is crossed by the valleys of Beaver Creek and a tributary of that stream, which heads in the township to the north. Between these valleys is a high ridge containing several prominent points, which are capped with sandstone. The altitude of the highest point in this township is about 400 feet above that of the lowest part. Although the relief is great, the township is generally grass covered, and most of the slopes are gentle. The rocks are generally covered with glacial drift.

The glacial drift ranges in thickness from a few inches to 30 feet and is composed of pebbles of igneous and sedimentary rock of almost

¹⁴ On Plate XXVI section 830 is incorrectly labeled 823.

every description. In places the fine material has been carried away by subsequent erosion, leaving only large boulders of crystalline rock. A few limestone boulders have been found pitted and honeycombed by weathering, but generally the granites predominate at the surface. Exposures of the underlying rocks are poor and widely separated. In secs. 3 and 4 high hills are capped with sandstone. Elsewhere exposures of the stratified rocks are confined to little cut banks along streams or in gullies. The only formation represented is the Fort Union. This formation is lignite-bearing wherever known, and in this township at least three beds of lignite were noted in its exposed portions, although difficulty was experienced in mapping them because of the grass-covered slopes and the scarcity of outcrops. The lowest bed exposed is bed CC, which has an average thickness of over 5 feet in this part of the field. Measurements of this bed were obtained at locations 836 and 837. (See Pl. XXVI.) Elsewhere in the township the outcrop of this bed is concealed, although it is probable that location 832 is on the outcrop of this bed also, as a small amount of clinker was found here. At the horizon of bed DD some large pieces of lignite were found on the surface at location 834, but owing to the swampy condition of the place no section of the bed could be obtained. The highest bed of lignite exposed is bed EE, which was noted at locations 831 (see Pl. XXVI) and 835. No measurement of thickness is given for location 835. At location 833, which is outside of the reservation, bed EE has been mined by striping. The section at this place is as follows:

Section of bed EE at location 833, in the SW. $\frac{1}{4}$ sec. 14, T. 146 N., R. 89 W.

Shale.	Ft.	in.
Lignite-----		6
Shale -----	1	
Lignite-----	2	2
Bottom covered by slump.		
	3	8

T. 147 N., R. 88 W.

Only that portion of T. 147 N., R. 88 W., which lies southwest of Missouri River is described here. It comprises parts of secs. 19, 30, 31, 32, 34, and 35.

The greater part of this township includes the flood plain of Missouri River. The southwestern part of sec. 31 lies on a terrace which slopes gently toward the flood plain. Between the terrace and the flood plain is a bluff averaging 50 or 60 feet in height but not so abrupt as to cause exposures in very many places. The bluff and the terrace are generally grass covered, whereas the flood plain of the river is densely covered with undergrowth. In places it is swampy, indicating cut-off meanders of the old stream.

The surface is largely covered with recent alluvium. In places, however, the ground is composed of glacial drift, and only in a few localities do the sedimentary rocks appear at the surface.

One bed of lignite corresponding to bed CC in the township immediately to the south has been mapped in sec. 31 of this township and was measured at locations 840 and 841. In a coulee in the center of sec. 31 this bed has been burned on this outcrop. Section 840 is incomplete owing to weathering of the bed at this place, and only 1 foot 8 inches was found. Section 841, which is also incomplete, shows 4 feet of lignite. (See Pl. XXVI.)

T. 146 N., R. 88 W.

The part of T. 146 N., R. 88 W., that lies within the Fort Berthold Reservation is rolling and generally grass covered. Beaver Creek flows through the western part from south to north and empties into Missouri River. Its valley is broadly U-shaped, and most of the slopes are gentle. The lower part of the stream for a mile or so contains flowing water the year around. Above this point the stream contains water in pools. Missouri River cuts the north line of the township in two places, but the entire width of the river does not come within the boundaries at any place. In secs. 4 and 5 bluffs 60 to 70 feet high are being rapidly undercut by the river, which is gradually moving its channel southward. A small tributary of Missouri River in sec. 4 heads in the highest hills in this township. It contains water in pools, from several springs, and in sec. 9 its valley is very steep-sided. It probably contains the best exposures of the rocks in this township.

The formation is generally covered with glacial drift from a few inches to 30 feet or more in thickness. Enough exposures were found, however, to indicate that the rocks lie nearly flat, with probably a slight dip to the northwest of less than 10 feet to the mile. The formation at the surface is the Fort Union and contains at least three beds of lignite in the exposed section in this township. The base of the exposed section is probably 160 feet above the base of the formation. The length of the stratigraphic section above Missouri River in this township amounts to about 225 feet, but a complete section could not be obtained owing to the cover of glacial drift or alluvium. Most of the strata are composed of sandy shale and sandstone with a few carbonaceous layers and a few beds of lignite.

The lowest bed of lignite mapped in this township, bed CC, crops out in sec. 5 in the bluff at the mouth of Beaver Creek on Missouri River, at location 847, where it contains 4 feet 8 inches of lignite. (See Pl. XXVI.) At this place the entire bed is not exposed, for the upper part has been eroded, and its surface is irregular and overlain by drift. At location 848, in sec. 4, the conditions

are similar and only 4 feet of this bed could be measured. The thickest known portion of this bed lies in the southern part of sec. 4 and the northern part of sec. 9. A section measured at location 849, in the SW. $\frac{1}{4}$ sec. 4 shows over 4 feet of lignite. (See Pl. XXVI.) Another section of this bed was obtained at location 843. Locations 846 and 852 are at the horizon of bed CC, but no section could be obtained at these places, and only fragments of lignite indicate its presence. Bed DD was measured at locations 845, 850, and 851. (See Pl. XXVI.) This bed is thicker and of better quality in this township than in the townships to the west. The highest bed of lignite exposed in this township is bed EE. It has been burned along the outcrop and causes a large amount of clinker. A section of this bed was measured at location 844, where it contains over 6 feet of lignite. (See Pl. XXVI.)



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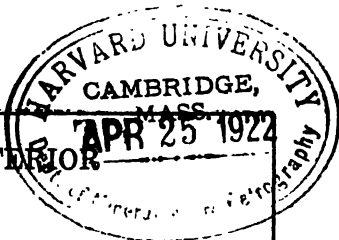
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DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director



BULLETIN 726—E

**GEOLOGIC STRUCTURE OF PARTS OF
NEW MEXICO**

BY

N. H. DARTON

Contributions to economic geology, 1921, Part II
(Pages 173-275)

Published March 31, 1922



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CONTENTS.

	Page.
Introduction.....	173
Sedimentary rocks of New Mexico.....	175
General succession.....	175
Older Paleozoic rocks.....	179
Magdalena group (Pennsylvanian).....	179
Permian "Red Beds" (Manzano group).....	181
Abo sandstone.....	181
Chupadera formation.....	181
Triassic "Red Beds".....	182
La Plata group (Jurassic).....	184
Wingate sandstone.....	184
Todilto formation.....	184
Navajo sandstone.....	184
Morrison formation (Cretaceous?).....	184
Limestones and sandstones of Comanche (Lower Cretaceous) age.....	185
Dakota sandstone (Upper Cretaceous).....	185
Mancos shale and contemporaneous Upper Cretaceous formations.....	185
Mesaverde group and corresponding and younger Cretaceous rocks.....	185
Early Tertiary (Eocene) deposits.....	186
Later Tertiary deposits.....	186
Quaternary deposits.....	187
General stratigraphic conditions.....	187
Structural and stratigraphic relations.....	189
Northeastern counties.....	189
General relations.....	189
Stratigraphy.....	190
Local structure.....	192
Deep borings.....	192
Central eastern counties.....	194
General relations.....	194
Stratigraphy.....	195
Local domes.....	195
Deep borings.....	197
Rocky Mountains.....	200
East-central plateau region.....	201
General relations.....	201
Stratigraphy.....	201
Local structure.....	202
Deep borings.....	203
Estancia Valley.....	206
Sacramento Cuesta.....	207
General relations.....	207
Stratigraphy.....	207
Local structure.....	209
Borings.....	210

Structural and stratigraphic relations—Continued.

	Page.
Pecos Valley in Chaves and Eddy counties.....	210
General relations.....	210
Stratigraphy.....	210
Local structure.....	211
Oil.....	211
Deep borings.....	212
Staked Plains region.....	216
Cerrillos Basin.....	216
Upper Rio Grande valley.....	217
Sandia and Manzano mountains and Sierra de los Pinos.....	217
General relations.....	217
Deep borings.....	219
Rio Grande valley in central New Mexico.....	220
Chupadera Mesa.....	221
General relations.....	221
Stratigraphy.....	221
Local structure.....	221
Tularosa Basin.....	223
General relations.....	223
Stratigraphy.....	223
Local structure.....	226
Deep borings.....	227
San Andres Mountains.....	229
Jornada del Muerto.....	229
General relations.....	229
Local structure.....	231
Lower Rio Grande valley.....	232
Eastern Socorro County.....	234
General relations.....	234
Local structure.....	234
Cerrillos del Coyote to Carthage.....	234
Cibola Cone syncline and fault.....	237
Valle del Ojo de la Parida.....	237
Taylor coal basin.....	238
Prairie Spring anticline.....	238
Basin of Arroyo Chupadero.....	239
Oscura anticline.....	239
Joyita Hills.....	239
Socorro and Lemitar mountains.....	240
Nacimiento uplift.....	241
General relations.....	241
Stratigraphy.....	241
Local structure.....	242
Chama Basin.....	242
General relations.....	242
Stratigraphy.....	244
Local structure.....	244
Valle Grande area.....	245
San Juan Basin.....	245
General relations.....	245
Oil.....	246
Local structure.....	247
Deep borings.....	249

Structural and stratigraphic relations—Continued.		Page.
Zuni Mountains.....		253
General relations.....		253
Stratigraphy.....		254
Deep borings.....		254
Gallup-Zuni Basin.....		257
General relations.....		257
Stratigraphy.....		259
Local structure.....		259
Deep borings.....		260
East-central Valencia County.....		262
General relations.....		262
Stratigraphy.....		263
Local structure.....		264
Deep borings.....		264
North-central Socorro County.....		265
General relations.....		265
Stratigraphy.....		265
Local structure.....		266
Borings.....		266
West-central volcanic area.....		267
Plains of San Agustin.....		268
Fairview to Lake Valley.....		268
Southwestern counties.....		269
General relations.....		269
Cooks Range.....		270
Florida Mountains.....		270
Florida Plains.....		270
Goodsight Mountains.....		272
Tres Hermanas Mountains and adjoining plains.....		272
Cedar Grove Mountains and Carrizalillo Hills.....		273
Klondike Hills.....		273
Victorio Mountains.....		273
Ridges in northwest corner of Luna County.....		274
Big Hatchet Mountains.....		274
Little Hatchet Mountains.....		274
Animas Mountain and San Luis Range.....		275
Peloncillo Mountains.....		275
Pyramid Mountains.....		275

ILLUSTRATIONS.

	Page.
PLATE XXX. Map of New Mexico.....	174
XXXI. A, Bliss sandstone, San Andres Mountains, N. Mex.; B, Coyote Butte, N. Mex.....	188
XXXII. A, Bluewater Canyon, N. Mex.; B, Inscription Rock, N. Mex..	188
XXXIII. A, Wingate sandstone at Rito, N. Mex.; B, Sandstone of Glorieta Mesa, near La Cuesta, N. Mex.....	188
XXXIV. Sandstones at Navajo Church, N. Mex.....	189

	Page.
PLATE XXXV. <i>A</i> , Navajo and Dakota sandstones at Atarque, N. Mex.; <i>B</i> , Dakota sandstone at Bluewater Falls, N. Mex.....	196
XXXVI. <i>A</i> , Dome near San Ignacio, N. Mex.; <i>B</i> , West front of Sacramento Mountains, N. Mex.....	197
XXXVII. West front of Sandia Mountains at Bernalillo, N. Mex.....	218
XXXVIII. Geologic map of Sandia and Manzano mountains and Sierra de los Pinos, N. Mex.....	218
XXXIX. <i>A</i> , Dakota sandstone on west slope of Cerrillos Basin, N. Mex.; <i>B</i> , West front of Chupadera Mesa, N. Mex.....	220
XL. Geologic map of Tularosa Basin, N. Mex.....	224
XLI. Pilot Knob on west slope of San Andres Mountains, N. Mex..	228
XLII. Geologic map of Jornada del Muerto, N. Mex.....	230
XLIII. Geologic map of part of Socorro County, N. Mex.....	234
XLIV. <i>A</i> , Base of Magdalena group southeast of Socorro, N. Mex.; <i>B</i> , Upturned Magdalena beds at Ojo de Amado, east-northeast of Socorro, N. Mex.....	236
XLV. <i>A</i> , Mesa del Yaso, N. Mex.; <i>B</i> , Sierrita Mesa, Nacimiento uplift, N. Mex.....	237
XLVI. <i>A</i> , Pyramid Rock, N. Mex.; <i>B</i> , Uplift at Atarque, N. Mex..	254
XLVII. <i>A</i> , West slope of Zuni uplift at Nutria, N. Mex.; <i>B</i> , Northwest slope of Zuni uplift east of Gallup, N. Mex.....	255
XLVIII. Geologic map of parts of Valencia and Socorro counties, N. Mex.	262
XLIX. Sections across Sierra Lucero in Valencia and Socorro counties, N. Mex.....	264
L. Map showing structure of valleys of Rio Salado and Alamosa Creek, Socorro County, N. Mex.....	266
FIGURE 16. Map showing the major structure of northeastern New Mexico....	189
17. Section across Colfax and Union counties, N. Mex.....	190
18. Section from Pedernal Mountain across Guadalupe, and Quay counties, N. Mex.....	195
19. Map of Esterito dome, Guadalupe County, N. Mex.....	196
20. Section from south end of Rocky Mountains to Cuervo Butte, Guadalupe County, N. Mex.....	197
21. Generalized sections across the Rocky Mountains in New Mexico..	201
22. Sections across the plateaus of southeastern Santa Fe County, southwestern San Miguel County, and eastern Tarrant County, N. Mex.....	202
23. Sections across the Sacramento Cuesta and Guadalupe Mountains, N. Mex.....	208
24. Sketch section of anticlines and fault between Alamogordo and High Rolls, N. Mex.....	209
25. Map showing relation of anticline in Tijeras coal field, N. Mex...	218
26. Sections across the Sandia and Manzano mountains and the Sierra de los Pinos, N. Mex.....	219
27. Sections across Chupadera Mesa, N. Mex.....	222
28. Sections across Tularosa Basin, N. Mex.....	225
29. Log of deep boring at Oscuro, N. Mex.....	228
30. Logs of two railroad wells at Carrizozo, N. Mex.....	228
31. Sections across the Jornada del Muerto, N. Mex.....	230
32. Sections across eastern Socorro County, N. Mex.....	235
33. Sketch section across the Joyita Hills, Socorro County, N. Mex....	240
34. Sections across San Pedro Mountain and the Nacimiento Range, N. Mex.....	242

	Page.
FIGURE 35. Map showing structure in part of Rio Arriba County, N. Mex.....	243
36. Section across the plateau in Rio Arriba County, N. Mex.....	245
37. Section along San Juan River, San Juan County, N. Mex.....	246
38. Geologic sketch map of part of McKinley County, N. Mex.....	248
39. Map showing structure of part of northwestern New Mexico.....	255
40. Sections across the Zuni Mountain uplift, N. Mex.....	256
41. Sections across the Gallup-Zuni Basin, N. Mex.....	258
42. Section across north-central Socorro County, N. Mex.....	267
43. Section from the Mimbres Mountains eastward through Kingston and Hillsboro, N. Mex.....	269
44. Sections across the Florida Mountains, Luna County, N. Mex....	271
45. Section through the Snake Hills, southwest of Deming, Luna County, N. Mex.....	272
46. Section through the Klondike Hills, Luna County, N. Mex.....	273
47. Section across the Victorio Mountains, south of Gage, Luna County, N. Mex.....	273
48. Sketch section across the north end of the Big Hatchet Mountains, Hidalgo County, N. Mex.....	274

GEOLOGIC STRUCTURE OF PARTS OF NEW MEXICO.

By N. H. DARTON.

INTRODUCTION.

Although New Mexico is not yet producing oil, wide areas of the State are underlain by rocks of the same age as those which yield oil and gas in adjoining States to the east, and in many places the structural conditions are favorable for the accumulation of oil and gas if they are present. So far the only notable discovery of oil has been that made near Dayton, in Pecos Valley, where some artesian wells yield small amounts, but indications of oil have been reported in several parts of the State. Many deep holes have been bored for water and a few for oil, but most of them have been in places where the structure is not favorable for oil or gas or were not deep enough to test the possibilities of all the strata.

This report is published in order to place in the hands of oil and gas geologists the information now in hand as to the structural features of New Mexico. Many of the data are new and are by-products of investigations made with objects very different from those of the geologist in search of new oil fields. During the last four years I have studied the stratigraphy and depositional history of the "Red Beds" region of the Southwest, including a large part of New Mexico, with special reference to the determination of the centers of greatest salt deposition. The principal aim of the work was to discover areas in which potash salts also may have been locally deposited. In the course of these studies reconnaissance was extended over large portions of New Mexico, especially in areas where the stratigraphy and structure were but little known. The results of this work, together with information previously available, are embodied in a forthcoming report on the geology of the "Red Beds" and associated formations of New Mexico, to be accompanied by a colored geologic map on a topographic base founded in large part upon original topographic sketches.

On account of the great number of requests received by the Geological Survey for information relating to the general stratigraphy and structure of New Mexico, it has been decided to publish at this time the data on the character and thickness of the formations and the general structure for the special use of oil geologists in a report with simple maps that may be placed in the hands of the public in advance of the engraving of the more elaborate geologic map of the

State. Emphasis must be laid on the facts that the field examinations were not made for the purpose of finding areas favorable for the occurrence of oil and that the work was done largely by methods less detailed than those required in the search for oil and gas, especially in the recognition and mapping of minor anticlines or domes that might be important centers of oil or gas accumulation. However, it is believed that this report will be of value as a guide to the regions in which the stratigraphy of the formations appears more favorable and as a presentation of the larger structural features. Doubtless it will also indicate some of the areas where minor folds are to be looked for. At the same time many portions of the State are differentiated as offering no encouragement to prospectors for oil.

In general, New Mexico has not been regarded with favor by most of the oil and gas geologists of the country, notwithstanding the fact that surface indications of oil are known at several points in the State and oil in small amounts has been found near Dayton and Seven Lakes. This disfavor is not without some foundation, for there are several adverse considerations, of which the following are perhaps the most important: (1) In New Mexico the Cretaceous formations, which are the sources of most of the oil in the Rocky Mountain States, are present only in relatively small areas, in many of which their position and structure are not favorable for oil; (2) in the many wide areas where the Cretaceous formations are absent, particularly in the central and northern parts of the State, the Paleozoic formations are of no great aggregate thickness, the Carboniferous lying directly on the pre-Cambrian crystalline rocks; (3) the Jurassic, Triassic, and Permian formations in general carry but little carbonaceous matter, the thick succession of these strata being singularly deficient in such organic débris as is generally regarded as the mother substance of petroleum; (4) through the central and southern portions of the State the folding and faulting are relatively pronounced, the pre-Cambrian crystalline rocks are brought up in the axes of the arches, the basins are comparatively narrow, and although minor folds undoubtedly are present, the marginal areas are in some places much faulted and cut by later lavas and many of the catchment areas are very small; and (5) finally, it is likely that in many areas, particularly in the older rocks and toward the southwest, carbonization of the organic débris in the formations has progressed so far as to preclude the survival of oil in commercial pools, though gas in considerable amounts may be present. The data on this fifth point are, however, very meager, so that it is not possible to state at the present time their bearing on the prospects in the different areas. The same condition exists in the Cretaceous rocks in some areas, notably in the Raton and Cerrillos coal fields. For the same reason also it seems probable that the Pennsylvanian rocks in the upper Pecos Valley east of Santa Fe and in a part of Bernalillo County may be too much

RESEARCH REPORTS ON THE HISTORY OF THE UNITED STATES

altered to encourage the prospector for oil. On the other hand, it is probable that the Cretaceous rocks in the San Juan Basin, except possibly near the Colorado line, and the Carboniferous beds in the eastern third of the State are not too greatly altered. In general the oil geologist may find it advantageous to consider the state of carbonization of the combustible *débris* of the coals and carbonaceous shales in most areas in advance of testing by the drill.

Although the "Red Beds" are nearly barren of oil-making materials they include sandstones which may be excellent reservoirs for the storage of oil that has migrated from more favorable strata, separated by considerable thicknesses of unproductive beds. The demonstrated presence of oil in the "Red Beds" of the Pecos Valley near Dayton encourages the hope that in some areas the sands in these unpromising rocks may be reservoirs for commercial deposits of oil, even where they are remote from strata rich in carbonaceous matter.

On the whole, the Carboniferous and Cretaceous areas of eastern New Mexico and the Cretaceous areas of the northwestern portion of the State, west of the Nacimientos uplift, probably offer greater encouragement for the discovery of commercial oil fields than other portions of the State. Oil, gas, or asphalt are present in these areas; the sedimentary formations attain considerable thicknesses; some of the associated strata are sufficiently rich in carbonaceous *débris*; and the presence of stresses, indicated by the major folding, makes it almost certain that examinations in detail will reveal minor anticlines and domes of the type most favorable for oil and gas.

SEDIMENTARY ROCKS OF NEW MEXICO.

GENERAL SUCCESSION.

The strata in New Mexico present a great thickness of beds from Cambrian to Recent in age, but portions of some of the geologic periods are not represented by deposits. The classification of most of the formations has been established by the work of several geologists, and this subject will be only briefly treated here, except as it is touched by my own investigations of the Triassic and Permian "Red Beds" and associated formations, for which some new classifications must be introduced. It is necessary to consider these matters briefly at this time, because in this report many new facts are presented in connection with the distribution and structure of the formations of Jurassic, Triassic, and Permian age. A more detailed discussion will be given in the fuller report now in preparation.

The following lists show the stratigraphic position, character, and thickness of the principal formations in different parts of New Mexico. It is not practicable to give them all in one table, because of the regional variations in the character of the deposits in this large State, which has an area of 122,634 square miles.

Formations in northeastern New Mexico.

Age.	Group and formation.		Character and general relations.	Average thickness (feet).
Recent.	Alluvium.		Sand, gravel, and clay.	50±
Pliocene and Miocene.	Santa Fe formation.		Sand, silt, gravel, and conglomerate.	150+
Eocene.	Raton formation.		Conglomerate and sandstone; local coal beds.	1,200-1,600
Eocene (?).	Gallsteo sandstone.		Sandstone and conglomerate. Relations to Raton formation unknown.	700+
Upper Cretaceous.	Montana group.	Vermejo formation.	Sandstone and shale, with coal beds.	0-375
		Trinidad sandstone.	Sandstone, gray to buff.	0-100
		Pierre shale.	Shale, mostly dark colored; upper beds sandy.	(?)
	Colorado group.	Apishapa shale.	Shale, in part limy.	500
		Timpas limestone.	Limestone, mostly impure.	50
		Carlile shale.	Shale, with concretions.	250
		Greenhorn limestone.	Limestone, slabby, and dark shale.	60
		Graneros shale.	Shale, dark.	150+
		Dakota sandstone.	Sandstone, gray to buff, hard.	100
Lower Cretaceous.	Purgatoire formation.		Sandstone, overlain by shale.	140
Cretaceous (?).	Morrison formation.		Shale, massive, mostly greenish gray, and intercalated sandstones.	150
Jurassic.	Todilto limestone.		Limestone; weathers thin bedded; locally overlain by 60 feet of gypsum.	0-85
	Wingate sandstone.		Sandstone, massive, light gray.	100
Triassic.	Dockum group.		Shales and sandstones, mostly red, containing locally, near the lower part, the Santa Rosa sandstone.	800+
Permian.	Manzano group.	Chupadera formation.	Limestone, sandstone, and gypsum.	600-1,200
		Abo sandstone.	Sandstone, mostly hard, slabby, brownish red.	600-800
Pennsylvanian.	Magdalena group.		Limestone, some shale, and sandstone.	600-1,200+
Pre-Cambrian.			Granite, schist, etc.	

Formations in northwestern New Mexico.

Age.	Group and formation.		Character and general relations.	Average thickness (feet).
Recent.	Alluvium.		Sand, gravel, and silt of river bottoms, desert floors, and fans.	0-50
Pliocene and Miocene.	Santa Fe formation.		Sand, gravel, silt, sandstone, and conglomerate.	450±
Eocene.	Wasatch formation.		Conglomerate, sandstone, and shale.	2,000+
	Torrejon formation.		Clay, sandy shale, and sandstones, hard and soft.	400
	Puerco formation.		Clay, sandy shale, and sandstones, hard and soft.	
Upper Cretaceous.	Ojo Alamos sandstone.		Sandstone, conglomeratic, with two conglomerate beds and shale lenses.	65-110
	Kirkland shale.		Shale. Includes Farmington sandstone member.	800-1,180
	Fruitland formation.		Sandstone and shale, with coal, sandy shales, and concretions.	190-290
	Pictured Cliffs sandstone.		Sandstone, copper-colored, also yellowish to light gray or brown.	50-275
	Lewis shale.		Shale, greenish gray, sandy, with local streaks of yellowish calcareous shale.	200-1,200
	Mesaverde group.	Cliff House sandstone.	Sandstone, with some shale beds.	400+
		Menefee formation.	Shale, with sandstone and coal beds.	600-1,200
		Point Lookout sandstone.	Sandstone, with some shale beds.	300
	Mancos shale.		Shale, with sandstone members.	1,000-2,000
	Dakota sandstone.		Sandstone, gray to buff, hard, massive.	75-125
Cretaceous (?).	McElmo formation to west; Morrison formation to east.		Shale, light-colored, and sandstone	200
Jurassic.	La Plata group.	Navajo sandstone.	Sandstone, massive, pink to gray.	600
		Todilto limestone.	Limestone, mostly very thin-bedded and 15 feet thick; locally at top a gypsum bed 80 feet thick.	
		Wingate sandstone.	Sandstone, massive, pink.	80-400

Formations in northwestern New Mexico—Continued.

Age.	Group and formation.	Character and general relations.	Average thickness (feet).
Triassic.	Chinle formation.	Shale, largely red, some gray.	850
	Shinarump conglomerate to west; Poleo sandstone in Nacimiento uplift.	Sandstone, mostly coarse (Shinarump conglomerate, 50-100 feet); in Nacimiento uplift sandstone, massive gray, hard (Poleo sandstone, 120 feet).	50-120
	Moenkopi formation.	Shale, in part sandy, mostly red.	400-800
Permian.	Manzano group. Chupadera formation.	Limestone, gray sandstone, gypsum, and soft red sandstone.	600+
	Abo sandstone.	Sandstone, hard, slabby, brownish red; limestone near base.	700+
Pennsylvanian.	Magdalena group.	Limestone; some shale and sandstone.	0-200+
Pre-Cambrian.		Granite and schist.	

Formations in southern New Mexico.

Age.	Group and formation.	Character and general relations.	Average thickness (feet).
Recent.	Alluvium.	Sand, gravel, and silt of river bottoms, desert floors, and fans.	0-1,000
Pleistocene.	Palomas gravel.	Sand, gravel, and conglomerate.	450
Eocene (?).		Conglomerate.	120+
Upper Cretaceous.	Mesaverde (?) formation.	Sandstone, with coal beds.	600
	Mancos shale (?).	Shale with sandstone layers.	940-2,000
Upper Cretaceous(?)	Beartooth quartzite.	Quartzite, with some shale.	90-125
Lower Cretaceous.	Sarten sandstone.	Sandstone.	0-300
		Limestones, shales, and sandstones.	800+
Triassic (?).	Lobo formation.	Shales, conglomerate, and limestone.	0-350
Triassic.		Red shales.	0-600
Permian.	Manzano group. Chupadera formation.	Limestone, gypsum, and gray and red sandstone. Gym limestone of Daming quadrangle is equivalent to part of Chupadera.	1,200-3,000+
	Abo sandstone.	Sandstone, slabby, brown-red. Thins out near Hueco Mountains and to southwest.	0-600

Formations in southern New Mexico—Continued.

Age.	Group and formation.	Character and general relations.	Average thickness (feet).
Pennsylvanian.	Magdalena group.	Limestone, with some shale and sandstone, especially in lower part.	1,000-2,500
Mississippian.	Lake Valley limestone.	Limestone. Absent north of latitude 34° 30'. (Combined with Magdalena as Fierro limestone in Silver City region.)	0-80
Devonian.	Percha shale.	Shale. Absent north of latitude 33° 30'.	0-300+
Silurian.	Fuselman limestone.	Limestone, massive. Absent north of latitude 33° 30'.	0-1,000
Ordovician.	Montoya limestone.	Limestone, with cherty members above, dark and massive below. Absent north of latitude 33° 40'.	0-250
	El Paso limestone.	Limestone, slabby; weathers light gray. Absent north of latitude 33° 40'.	0-1,000
Cambrian.	Bliss sandstone.	Sandstone, massive to slabby, glauconitic. Absent north of latitude 33° 40'.	0-300
Pre-Cambrian.		Granite, schist, etc.	

OLDER PALEOZOIC ROCKS.

The distribution and classification of formations ranging in age from the Cambrian to the Mississippian have been presented in a previous publication.¹ Since that paper was written it has been found that the full sequence of the limestones and shales of these periods is exposed in the north end of Big Hatchet Mountain and near Gabilan Peak, in Grant County. Their character and relations in the Tularosa Basin, the Sacramento Mountains, the Jornada del Muerto region, and the southwest corner of New Mexico are treated in the sections on those regions in this report. It is rather unlikely that any rocks older than Carboniferous will be found to produce oil in this part of the continent.

MAGDALENA GROUP (PENNSYLVANIAN).

The Magdalena group is conspicuous at many places in New Mexico, notably in the Rocky Mountains, the Sandia, Manzano, and Pinos mountains, the Nacimiento uplift, the Magdalena, Mimbres, San Andres, and Sacramento mountains, and the Silver City and El Rito districts. It underlies a large part of the State and will be found in many well borings, although in the eastern part of the State it lies very deep. Limestone is the most conspicuous feature of the group.

¹ Darton, N. H., A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof. Paper 108, pp. 31-55, 1917.

but interbedded sandstones and shales occur in all sections; along the east side of the Rocky Mountains in the northern part of the State the Magdalena consists mainly of a thick body of gray to red sandstone. In the Sandia Mountains the group has been divided into the Sandia formation below and the Madera limestone above. Although the lower part of the Magdalena generally contains much sandstone the stratigraphic position of the sandstone beds and the transition from one member to the other differ at different localities. Locally the group can be divided into three or four formations, some of them separated by apparent unconformities. No faunal distinctions have been established in these formations, although eventually the fossils may indicate desirable subdivisions.

In the uppermost portion of the Magdalena group, or perhaps the basal portion of the overlying Abo sandstone, near Rio Salado, west of the Ladrone Mountains, D. E. Winchester² found plants which David White regards as probably Permian. The material is fragmentary but includes *Odontopteris* probably *O. obtusa* Brongniart, *Neuropteris* aff. *N. gleichenoides*, *Sphenopteris* sp., *Callipteris* cf. *C. lyratifolia*, *Taeniopteris*, *Saportaea*?, *Walchia pinnaeformis*, *Walchia gracilis*, *Gomphostrobus bifidus*, *Araucarites*, *Trigonocarpon* sp., and other fragments less clearly identifiable. Mr. White says: "Notwithstanding the insufficiency of much of the material for the specific and in part the generic identification of the types, the evidence in hand points very strongly to the Permian age of the flora, and there is little room for doubt that the collection of material more adequate for satisfactory determination will prove conclusively that the containing shale is Permian."

In the overlying bed of limestone, 4 feet thick, presumably at the base of the Abo sandstone, though not certainly, as the overlying beds are hidden by terrace deposits, fossils were collected which were it not for the evidence of the fossil plants G. H. Girty would regard as Pennsylvanian. They are as follows:

Lophophyllum profundum.
Fistulipora sp.
 Crinoid stems.
Fenestella sp.
Pinnatopora sp.
Polypora sp.
Stenopora carbonaria.
Derbya robusta.
Productus nebraskensis.
Productus cora.
Productus semireticulatus.
Marginifera?
Composita subtilita.
Chonetes verneuillanus.

Pustula semipunctata?
Pustula nebraskensis.
Pugnax osagensis.
Dielasma bovidens.
Spiriferina kentuckyensis.
Spirifer cameratus.
Spirifer rockymontanus.
Squamularia perplexa.
Ambocoelia planiconvexa.
Cliothyridina orbicularis?
Platyceras parvum?
Griffithides? sp.
 Fish tooth.

² Personal communication.

PERMIAN "RED BEDS" (MANZANO GROUP).

Abo sandstone.—The Abo sandstone, differentiated by W. T. Lee,³ is the basal formation of the Manzano group. It has been found to be continuous throughout New Mexico but apparently thins out near the Texas line, in the south-central part of Otero County. It has very distinctive characteristics at most places and a uniform stratigraphic position between the Magdalena group and Chupadera formation. These features are both lost, however, in the Chama Basin and along the Rocky Mountain uplift north of Mora, where the formation may perhaps be undistinguishable from the adjoining red strata. In most places the Abo formation appears to be unconformable to the Magdalena, but in other places there is an apparent gradation between them. The few data available on which to class the formation place it in the Permian. It lies immediately on or includes at its base the 4-foot limestone member overlying the plant-bearing beds of supposed Permian age west of the Ladrone Mountains referred to on page 180. Plants obtained by Lee, Stanton, and White near Canyoncito and Glorieta are regarded by David White as Permian, and there can be no question that the beds yielding them belong to the Abo. Fossils collected by me in 1902 in the basal beds of the formation in the axis of the Lucera anticline, in sec. 36, T. 6 S., R. 3 W., were identified by G. H. Girty as follows:⁴

Myalina permiana.

Myalina perattenuata.

Aviculipecten cf. *A. whitei*.

Bakewellia? sp.

Bulimorpha near *B. nitida*.

Spirorbis sp.

Mr. Girty regards these fossils as indicating the Permian age of the beds.

Chupadera formation.—The name Chupadera is here introduced for the upper part of the Manzano group, which Lee⁵ divided into the Yeso formation and San Andreas⁶ limestone. In mapping these deposits it was found that while Lee's subdivisions were discernible in places, it was impracticable to separate them generally. Although limestone is the conspicuous feature of the San Andres limestone, much of that subdivision consists of thick beds of gypsum and sandstone which are not well exposed in the type localities. In the future, wherever Lee's subdivisions can be recognized they will be treated as members of the Chupadera formation, instead of as distinct formations. The new name is taken from Chupadera Mesa, in central

³ Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, N. Mex.: U. S. Geol. Survey Bull. 389, p. 12, 1909.

⁴ Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 37, 1910.

⁵ Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, N. Mex.: U. S. Geol. Survey Bull. 389, pp. 12-17, 1909.

⁶ Now spelled San Andres.

New Mexico, a prominent topographic feature consisting of a very extensive capping of the formation 1,500 feet or more thick. (See Pl. XXXIX, B, p. 220.)

The limestones of the formation carry many fossils of the well-known Manzano fauna described by G. H. Girty,⁷ originally regarded as late Pennsylvanian but now believed to be Permian. The Chupadera formation overlies the Abo sandstone, which as above shown also presents evidence of Permian age, and I have traced it continuously southward into the Capitan and Delaware Mountain limestones of the Guadalupe Mountains of Texas, which are unquestionably Permian. The Gym limestone⁸ of the Luna County region represents a part of the Chupadera formation.

In the Nacimiento uplift and Chama Basin it has not been practicable to recognize the Chupadera formation in the succession of red beds lying between the Magdalena group and the Poleo sandstone (Triassic), so that for the present at least these beds in that region are treated as "Permian undivided," although they doubtless include a representative of the Triassic Moenkopi formation. Bones of Permian animals, however, occur a short distance below the Poleo sandstone near Coyote.

TRIASSIC "RED BEDS."

In a previous report⁹ I mapped the red shales in the northwestern part of New Mexico as the Moenkopi formation, Shinarump conglomerate, and Leroux formation, the last capped by the Wingate sandstone of Dutton, of supposed Jurassic age. Later work by Gregory¹⁰ extending into part of the same region showed the desirability of changing the name Leroux to Chinle. The Moenkopi was supposed to be Permian, but fossils found by B. S. Butler¹¹ in its probable extension into Utah are of Triassic age.

The recognition of these subdivisions farther east in New Mexico has not been entirely satisfactory so far. The Shinarump conglomerate appears to be represented in the Nacimiento-Chama-Cobre region by a massive sandstone which Huene¹² has called the Poleo sandstone, from Poleo Mesa, of which it forms the surface; and although to me this sandstone strongly suggests the sandstone of Glorieta Mesa (which belongs to the Chupadera formation), it contains Triassic plants at the old Cobre copper mine, near Abiquiu, as

⁷ Lee, W. T., and Girty, G. H., op. cit., pp. 41-136.

⁸ Darton, N. H., *Geology and underground water of Luna County, N. Mex.*: U. S. Geol. Survey Bull. 618, p. 35, 1916.

⁹ Darton, N. H., *A reconnaissance of parts of northwestern New Mexico and northern Arizona*: U. S. Geol. Survey Bull. 435, p. 12, 1910.

¹⁰ Gregory, H. E., *Geology of the Navajo country*: U. S. Geol. Survey Prof. Paper 93, pp. 42-48, 1917.

¹¹ Emery, W. B., *The Green River Desert section, Utah*: Am. Jour. Sci., 4th ser., vol. 46, p. 560, 1918.

¹² Huene, F. von, *Kurze Mitteilung über Perm, Trias und Jura in New Mexico*: Neues Jahrb., Beilage Band 32, pp. 730-739, 1911.

described by Newberry¹³ and by Fontaine and Knowlton.¹⁴ Triassic bones near Coyote have been described by Williston and Case.¹⁵ Above this Poleo sandstone, as I shall term it in this paper, are red shales supposed to belong to the Chinle formation, extending to the base of what is unmistakably the Wingate sandstone. Underlying the Poleo are red shales and sandstones about 1,000 feet thick, which doubtless include strata representing the Moenkopi, Chupadera, and Abo formations but in which so far I have not found distinctive features in this region to enable me to separate them.

Farther east in the State, east of Glorieta Mesa and the Hills of Pedernal, the strata overlying the Chupadera formation consist of 800 feet or more of red shales and sandstones representing the Dockum group, including near the bottom a resistant massive sandstone which is prominent in the mesas of Guadalupe County and along Pecos River at Santa Rosa. This sandstone appears to occur at about the horizon of the Shinarump conglomerate, but no definite correlation is possible, and I here propose for it, tentatively at least, the name Santa Rosa sandstone. Case¹⁶ has found in it, as well as in overlying strata, bones of Triassic age. I found supposed Unios¹⁷ in beds immediately above it 1 mile north of Santa Rosa. The underlying shales are of undetermined age and may be either Triassic or Permian. Near Carthage and 17 miles northeast of Socorro shales at about this horizon carry Triassic vertebrates,¹⁸ and 12 miles northeast of Socorro some red conglomerate just above the Chupadera formation yielded Permian bones.¹⁹ It appears likely, however, that most of the shales overlying the Chupadera formation are of Triassic age. In the Pecos Valley region in Eddy and Chaves counties the overlying series is several hundred feet thick, and its outcrop extends from the east bank of Pecos River to the edge of the Staked Plains. No satisfactory evidence has been found as to the age of these beds. This question has been discussed by Beede,²⁰ who showed that they are above the Guadalupe group of limestones (Permian), which near Carlsbad are in places uplifted and bared in broad, low anticlines. These overlying beds are probably of Lower Triassic age.

¹³ Newberry, J. S., Geological report, in Report of expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers in 1865 under Capt. J. N. Macomb, 1876.

¹⁴ Fontaine, W. M., and Knowlton, F. H., Notes on Triassic plants from New Mexico: U. S. Nat. Mus. Proc., vol. 13, No. 821, pp. 281-285, pls. 22-26, 1890.

¹⁵ Williston, S. W., and Case, E. C., The Permo-Carboniferous of northern New Mexico: Jour. Geology, vol. 20, pp. 1-12, 1912; Permo-Carboniferous vertebrates from New Mexico: Carnegie Inst. Pub. 181, 81 pp., 1913.

¹⁶ Case, E. C., The Red Beds between Wichita Falls, Tex., and Las Vegas, N. Mex., in relation to their vertebrate fauna: Jour. Geology, vol. 22, pp. 243-259, 1914.

¹⁷ Determined by T. W. Stanton.

¹⁸ Case, E. C., Personal letter; also Science, new ser., vol. 44, pp. 708-709, 1916.

¹⁹ Case, E. C., Science, new ser., vol. 44, p. 709, 1916.

²⁰ Beede, J. W., The correlation of the Guadalupean and the Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 131-140, 1910.

LA PLATA GROUP (JURASSIC).

Wingate sandstone.—The Wingate sandstone, the lowest formation of the La Plata group, with all its highly characteristic features, relations, and associates, has been found to continue eastward across northern New Mexico, being unmistakable at least as far east as the longitude of Las Vegas.

Todilto formation.—The characteristic very thin bedded Todilto limestone, in places very sandy, overlies the Wingate sandstone in northern New Mexico as far east as this formation was traced, to longitude 105°. In the Nacimiento and Sandia uplifts it is well exposed, with characteristic outcrops, as far east as points 8 miles east of Canjilon and 2 miles northwest of Abiquiu. It appears near Lamy and 5 miles southeast of Galisteo and extends along the south face of the Canadian escarpment southeast of Las Vegas. It is also prominent around the Zuni uplift and in the central eastern part of Valencia County.

A thick deposit of gypsum overlies the limestone of the Todilto formation in the Chama Basin and Nacimiento uplift, the San Jose Valley southwest of Albuquerque, the Sandia uplift east of Albuquerque, and the uplift west of Cerrillos. As this gypsum bed is overlain by the Navajo sandstone, which also overlies the typical Todilto limestone, the gypsum is regarded as a local development of the upper part of the Todilto limestone.

Navajo sandstone.—The Navajo sandstone of Gregory, the upper formation of the La Plata group, extends for some distance eastward in New Mexico and is conspicuous in the eastern part of Valencia County, where the massive gray sandstone that constitutes much of it is widely exposed about Laguna, Acoma, the Mesa Gigante, and the west side of Cebolleta Mesa. Its outcrop zone extends around the Zuni uplift. It was not recognized east of the Rio Grande, and if present in the Nacimiento uplift it is represented by chocolate-colored sandstone between the gypsum bed in the top of the Todilto formation and the greenish-gray clays that are believed to represent the Morrison formation.

MORRISON FORMATION (CRETACEOUS?).

Light-colored massive shales with local sandstone members underlying the Dakota sandstone in northern New Mexico are believed to represent the Morrison formation, of supposed early Cretaceous age. The McElmo formation, in part at least equivalent to the Morrison, has been mapped by Gregory in the northwestern part of the State, and the typical Morrison beds of Colorado have been traced far southward in the eastern counties. The pale greenish-gray clays near Laguna, in the Nacimiento uplift northwest of Albuquerque, west of Cerrillos, near Lamy and Las

Vegas, in San Miguel, Union, Mora, and Quay counties, and near Fort Stanton probably will all prove to be Morrison.

LIMESTONES AND SANDSTONES OF COMANCHE (LOWER CRETACEOUS) AGE.

In Grant and Luna counties and at Las Cornudas, northeast of El Paso, occur limestone, shale, and sandstone that contain Comanche fossils. The Sartén sandstone, north of Deming, is also of Comanche age. Similar sandstone with Comanche fossils crops out along the north edge of the Staked Plains and in the outlying mesas to the north, and the Purgatoire formation, underlying the Dakota sandstone in the northeastern part of the State, is of Comanche age.

DAKOTA SANDSTONE (UPPER CRETACEOUS).

The sandstone at the base of the Upper Cretaceous series is regarded as Dakota, and in places it yields plants of that age. In Union and Mora counties it is spread out widely in a great plateau which terminates to the south in the high Canadian escarpment.

MANCOS SHALE AND CONTEMPORANEOUS UPPER CRETACEOUS FORMATIONS.

The thick body of shale lying between the Dakota sandstone and the coal-bearing sandstones in northwestern New Mexico is called the Mancos shale, for apparently it is a stratigraphic unit. It comprises part of the Pierre shale of the Montana group and all of the Colorado group, which to the east is differentiated into the Niobrara formation and the Benton shale. In the north-central and north-eastern parts of the State these Upper Cretaceous deposits are still further subdivided, as shown in the table on page 176. Sandstones occur at several horizons in the Mancos, differing in position in different regions and locally carrying coal beds. Without detailed study it is difficult to separate the upper coal-bearing sandstones from the overlying Mesaverde group. I offer no new light on this problem. It was found that coal-bearing sandstones of Mancos age extend far south in the Rio Grande valley, the southernmost point being on the east line of T. 20 S., R. 3 E., 20 miles northeast of Las Cruces. The composition of the Mancos is favorable for the generation of oil.

MESAVERDE GROUP AND CORRESPONDING AND YOUNGER CRETACEOUS ROCKS.

The thick series of sandstones with coal beds that make up the Mesaverde group, of Montana age, is well represented in northwestern New Mexico, especially in the San Juan Basin, west of the Nacimiento uplift, where it is divided into three formations, named, in

ascending order, the Point Lookout sandstone, Menefee formation, and Cliff House sandstone. Coal-bearing rocks of Mesaverde and Mancos age are also present in the Cerrillos Basin and in the broad, shallow basin extending southward from Gallup, past Zuni, to the head of the Salado and Alamosa drainage basins, also in the small basins of Carthage, Tijeras, the White Mountains, and Engle.

In northeastern New Mexico the Montana group is divided into three formations, known, in ascending order, as the Pierre shale, Trinidad sandstone, and Vermejo formation. The relations of the Trinidad sandstone and Vermejo formation to the Mesaverde have not been definitely determined. The fossil plants of the Vermejo formation suggest correlation with the Mesaverde, but the invertebrates and some of the stratigraphic data indicate that the Vermejo is younger than the Mesaverde and probably corresponds more closely with the Fox Hills.

The thick body of marine shale of Montana age (Lewis shale) that overlies the Mesaverde group in southern Colorado extends far southward in New Mexico but in some places diminishes greatly in thickness.

The succession of latest Cretaceous rocks in the San Juan Basin formerly designated "Laramie" has been subdivided into the Pictured Cliffs sandstone, Fruitland formation, Kirtland shale, and Ojo Alamo sandstone. Details regarding these formations, which overlie the Lewis shale, are given by Bauer.²¹

EARLY TERTIARY (EOCENE) DEPOSITS.

In the San Juan Basin there is a broad area filled with a succession of clays and sands comprising, in ascending order, the Puerco, Torrejon, and Wasatch formations. These beds lie unconformably on a somewhat uneven surface of Upper Cretaceous formations and overlap southward into the west slope of the Nacimiento uplift. The Galisteo sandstone, a reddish sandstone overlying the coal measures in the Cerrillos coal field, is thought to be early Tertiary. The Raton formation, which occupies the Raton coal basin, is also of that age.²² Early Tertiary sandstones or conglomerates overlie the Upper Cretaceous rocks in the Valle de la Parida, northeast of Socorro; along the west side of Miller Arroyo southeast of Socorro, about Carthage, in the Elephant Butte region; and in T. 20 S., R. 3 E., 20 miles northeast of Las Cruces.

LATER TERTIARY DEPOSITS.

The later Tertiary deposits in New Mexico comprise great accumulations of volcanic materials, including tuff, volcanic ash, agglomerate,

²¹ Bauer, C. M., Stratigraphy of part of the Chaco River valley: U. S. Geol. Survey Prof. Paper 98, pp. 269-278, 1916.

²² Lee, W. T., Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 101, pp. 56-61, 1917.

and lava flows, and also the Santa Fe formation, a deposit of loam, silt, sand, and gravel of Miocene and Pliocene age, occupying the Rio Grande basin in Taos, Rio Arriba, Santa Fe, Sandoval, and Bernalillo counties and extending southward for an unknown distance. These deposits cover a very large area in the State and conceal the structure of the sedimentary rocks, which no doubt underlie them in greater part. Some of these recent beds are tilted in various directions, but the structure which they might indicate should not be expected to continue downward in the underlying older rocks.

QUATERNARY DEPOSITS.

Sand, gravel, and clay of Quaternary age constitute the surface in many parts of New Mexico, especially in the river valleys and wide desert basins. Their thickness varies greatly, but in the wide area west of El Paso, about Deming, and in other similar valleys farther west they aggregate several hundred feet. Other broad areas are in the Tularosa Basin, the Jornada del Muerto, and the Plains of San Agustin. The "White Sands" west of Alamogordo consist of granular gypsum of Quaternary age, and other deposits of loose sand, mostly silica, occur in the same and other basins. Alluvial deposits occur along most of the streams, notably in the broad flood plain of the Rio Grande. Some of the valleys are also occupied by Quaternary lava flows, mostly lying on sand and gravel. The "Malpais" (badland) in Tularosa Basin west of Carrizozo is an example.

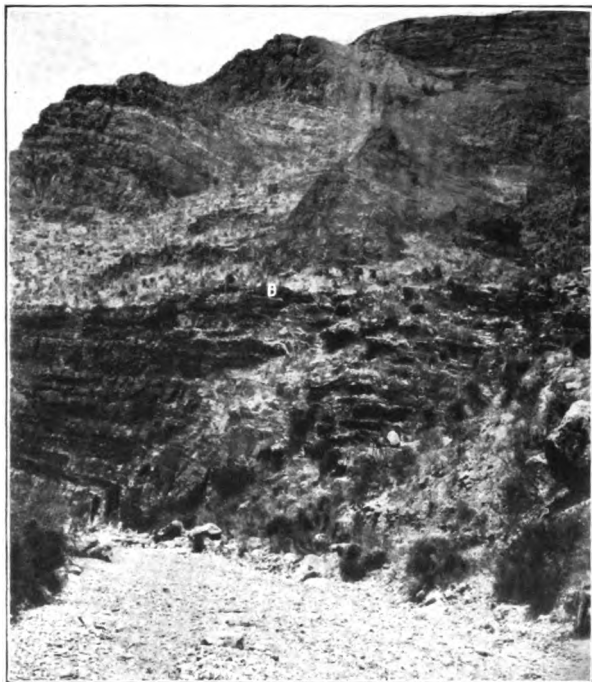
GENERAL STRATIGRAPHIC CONDITIONS.

Petroleum occurs in rocks only under certain favorable conditions of origin and storage, and naturally there are in New Mexico many districts in which the conditions are wholly unfavorable. The entire State is underlain by a basement of granite, gneiss, quartzite, and similar crystalline rocks which are barren of oil. These rocks in which it is hopeless to look for oil are uplifted to the surface in several areas, such as the Rocky Mountains, the San Andres Mountains, the Sierra Nacimiento, and the Hills of Pedernal. At other places they are overlain by limestones, sandstones, shale, red beds, volcanic rock, sands, and gravels, locally 5,000 feet thick. In texture, composition, and organic contents some of these strata are likely to be favorable for the development of oil, but although some porous beds are suitable for oil storage many such beds are far removed from any promising source of oil. Oil is believed to be produced from organic matter laid down with sands and clays in the original deposition, and in some of the beds in New Mexico there was never sufficient organic matter to produce any notable amount of oil. The "Red Beds," with thick bodies of red sandstone and shale and with deposits of gypsum, are nearly barren of organic matter and are not regarded by geologists as likely to contain oil unless the oil has migrated into

them and there found a suitable porous reservoir. In the very thick series of red beds the sandstones, however porous they may be, are thought generally to be too far above or below the mother rocks to have been reached by such oil as may have been generated in the beds containing more carbonaceous matter. Texture is a most important condition controlling oil accumulation, and the shales consisting of fine clay, the compact limestones, and some of the finer-grained sandstones have but little capacity for oil. Sand and gravel of the younger formations, valley fill, and slope talus are naturally very unfavorable materials. The volcanic rocks which cover a wide area in New Mexico should not be expected to carry oil, but in most areas these rocks are underlain by sedimentary strata of various kinds which may be reached by the drill.

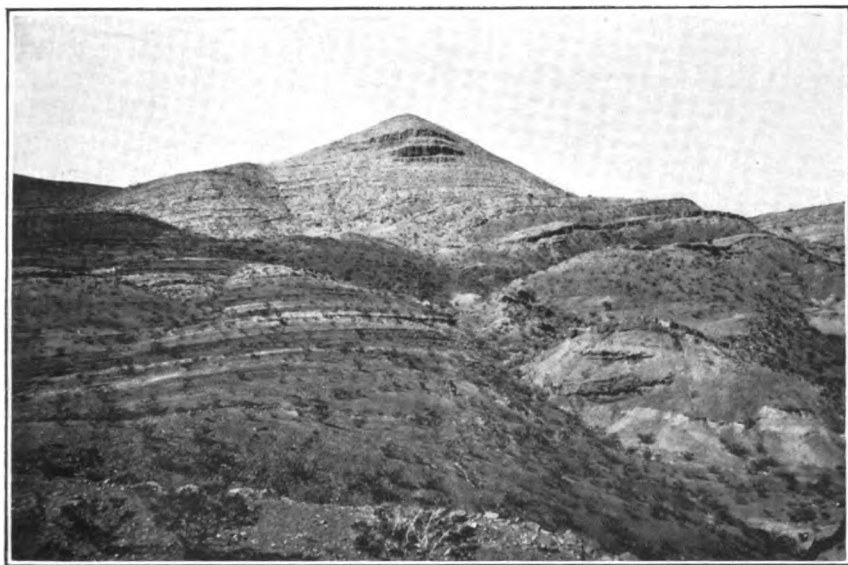
Of the sandstones in New Mexico those believed to be most likely to yield oil are members in the Mesaverde, Mancos, Chupadera, and Magdalena formations. The Bliss sandstone (see Pl. XXXI, A), 50 to 150 feet thick, at the base of the sedimentary succession, underlies the southern third of the State and does not contain much organic matter. Moreover, it is probably too much altered to contain oil. Sandstones in the Magdalena group, especially those in the lower part, are enveloped by strata that teem with remains of organic life and are not far removed from other beds that contain considerable carbonaceous matter. Some of the oil in Oklahoma and Kansas occurs in the eastward extension of this group. The sandstones in the Chupadera formation (see Pls. XXXI, B; XXXII, A; XXXIII, B) present stratigraphic conditions somewhat similar to those in the Magdalena group, though carbonaceous beds are but little in evidence. The oil at Dayton occurs in beds of the Chupadera far above the base of the formation. These sandstones are of wide extent under New Mexico, especially its eastern part, but to the north the amount of organic material in the associated strata is less, and in some of the central eastern area the formation is probably too near the surface to retain oil.

The red sandstones of the Navajo and Abo formations (see Pls. XXXI, B; XXXII, B; XXXIV) and the Wingate sandstone (Pl. XXXIII, A) carry very little organic matter and are not closely associated with carbonaceous strata. The Dakota sandstone (see Pl. XXXV, B, p. 196) where it lies under a cover of the Benton or Mancos shales, which contain much organic matter, appears to be favorable as a reservoir but has never been definitely proved to be oil-bearing in any region. In many portions of the State it lies at too shallow a depth, and in most areas it is saturated with water. The sandstones of the Mancos and Mesaverde formations are included in strata containing a very large amount of organic matter of various kinds, including coal. The oil at Seven Lakes is probably in the



A. BLISS SANDSTONE, SAN ANDRES MOUNTAINS, IN BENNETT CANYON, NORTHEAST OF LAS CRUCES, N. MEX.

B. Contact of Bliss sandstone and El Paso limestone.



B. COYOTE BUTTE, 12 MILES NORTHEAST OF SOCORRO, N. MEX.

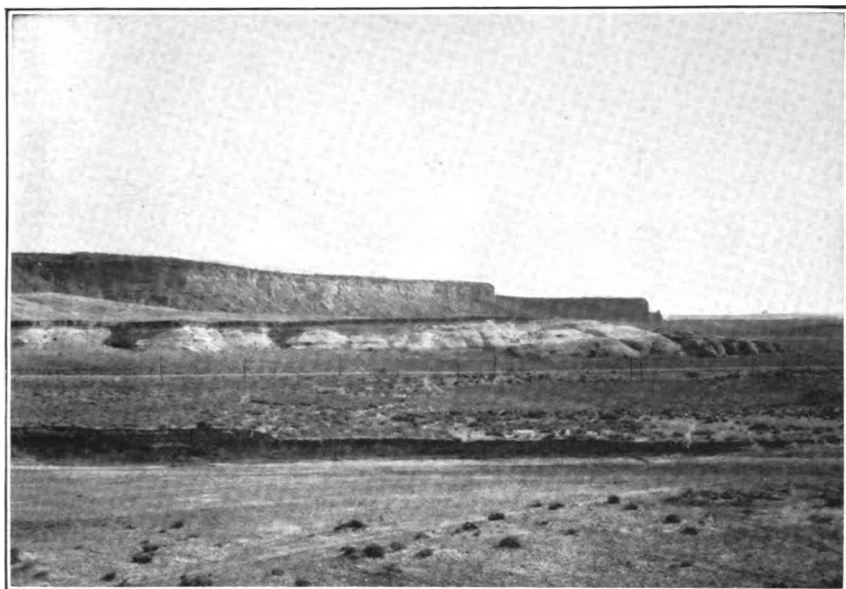
Limestone, sandstone, and gypsum of Chupadera formation.



A. BLUEWATER CANYON, N. MEX.
Limestone and sandstone of Chupadera formation.

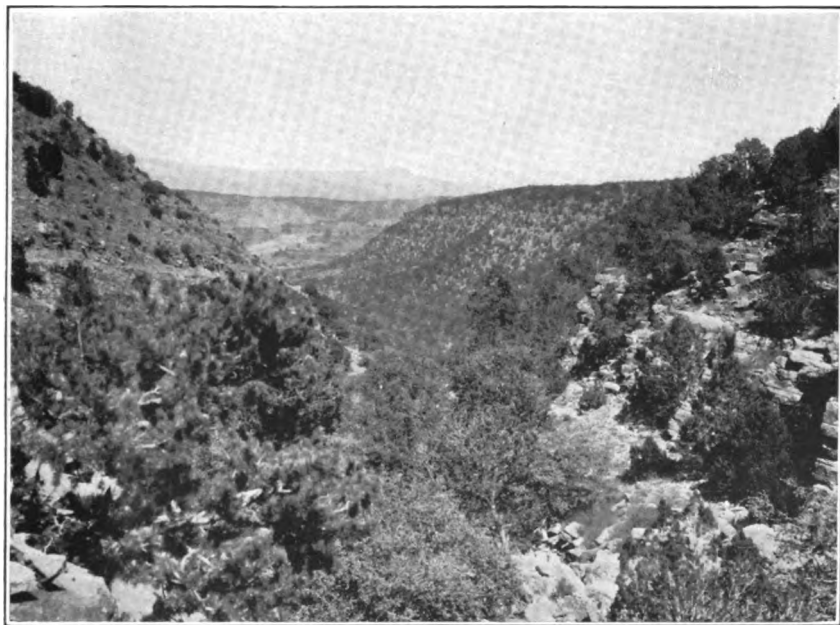


B. INSCRIPTION ROCK, N. MEX.
Navajo sandstone on southwest slope of Zuni Mountains.

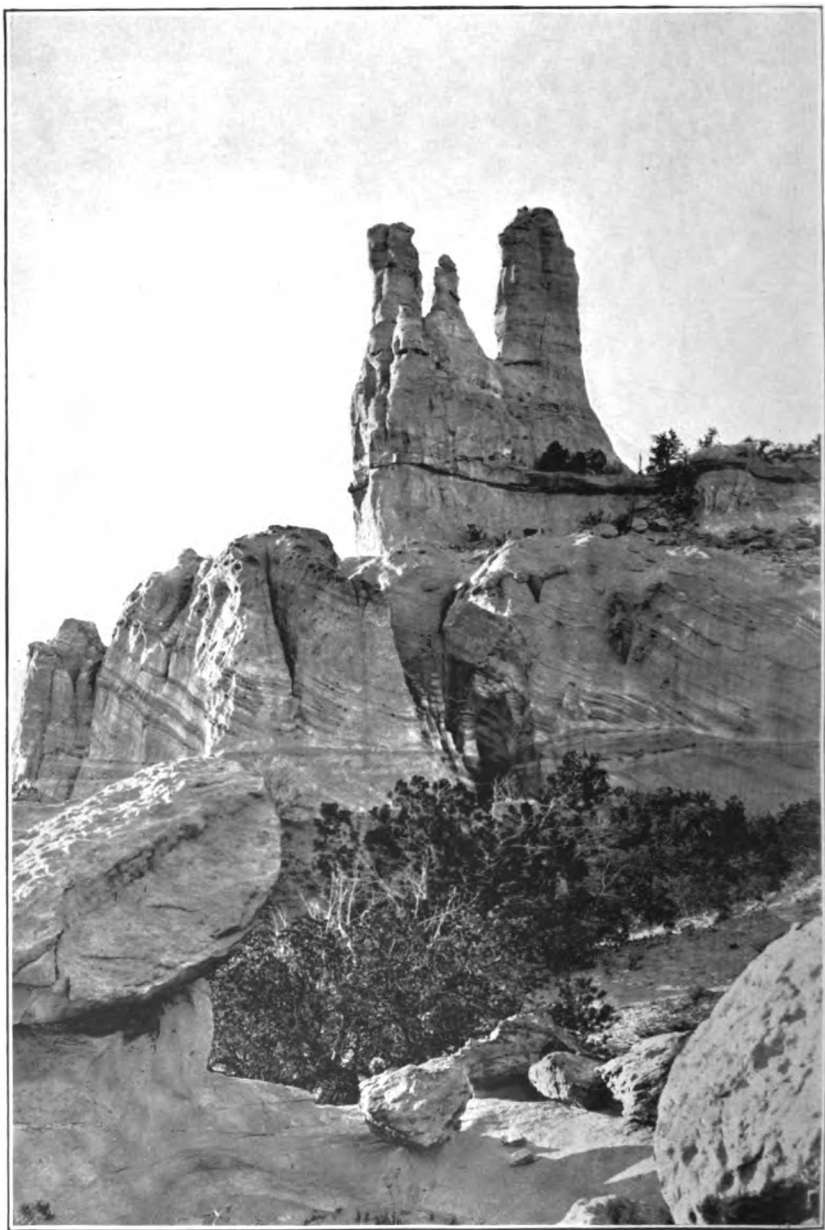


A. WINGATE SANDSTONE AT RITO, N. MEX.

Shows limestone and gypsum of Todilto formation; Navajo sandstone in the background.



B. SANDSTONE OF GLORIETA MESA, NEAR LA CUESTA, N. MEX.



SANDSTONES AT NAVAJO CHURCH, N. MEX.

Mesaverde formation. The capabilities of the Cretaceous sandstones above the Lewis shale as oil reservoirs can only be surmised. Some of the associated shales carry considerable organic matter.

STRUCTURAL AND STRATIGRAPHIC RELATIONS.

NORTHEASTERN COUNTIES.

GENERAL RELATIONS.

In the northeast corner of New Mexico, east of the Atchison, Topeka & Santa Fe Railway, in Union County and the eastern parts

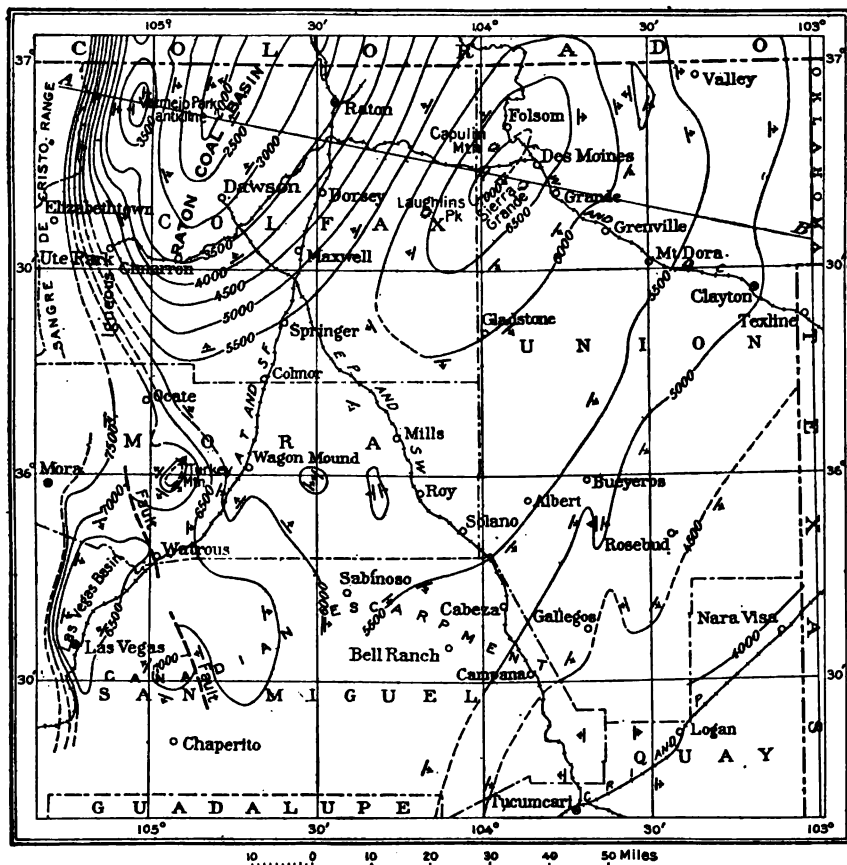
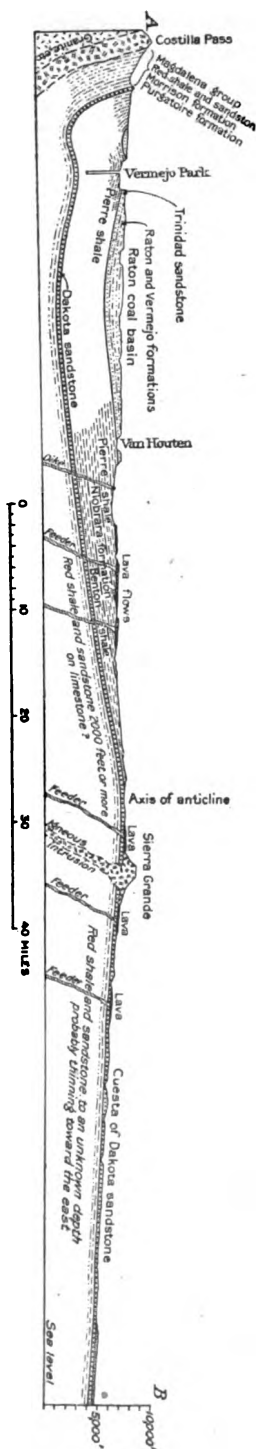


FIGURE 16.—Map showing the major structure of northeastern New Mexico by contours at the surface of the Dakota sandstone in Colfax, Union, Mora, and San Miguel counties. Contour interval, 500 feet. As but little of the area has been surveyed topographically, many of the elevations are only approximate. A-B, Line of section in figure 17.

of Colfax and Mora counties, the sedimentary rocks are uplifted in a broad dome or elongated arch with its highest part near Capulin Mountain and the Sierra Grande. To the west in Colfax County is the deep basin of the Raton coal field, from which the strata rise steeply to the Rocky Mountain front range, beyond. The broader features of the structure of this region are shown in figures 16 and 17.

FIGURE 17.—Section across Colfax and Union counties, N. Mex., along line A-B, figure 16.



Doubtless a detailed investigation of the region will reveal many minor irregularities of structure, such as local domes, anticlines, or terraces of the types in which oil and gas are found in other regions. Those situated on the crest or slopes of the broad arch are probably more promising than those farther down in the basins.

A large part of the surface of Union County consists of the Dakota sandstone, sloping eastward, covered to the east by Tertiary sands and gravels and to the north and west by sheets of lava. The deeper canyons cut through to underlying red beds. In Colfax and Mora counties the Dakota sandstone passes beneath the Benton and overlying shales, and in the Raton coal basin it is covered by several thousand feet of Cretaceous and early Tertiary beds. To the south, however, the strata rise somewhat, and the deep canyons of Canadian and Mora rivers reveal Triassic red shale (Dockum group).

STRATIGRAPHY.

The succession of rocks beneath the Dakota sandstone in northeastern New Mexico comprises sandstones and shales of Lower Cretaceous age and a thick body of red shales and sandstone (Triassic and Permian), probably including limestones in their lower part. In most places the Dakota is about 100 feet thick and the underlying gray shales and brown sandstones 125 feet thick. The deeper canyons cut through these rocks and also through a white to gray massive sandstone (Wingate sandstone) that underlies the area. Only the upper parts of the Triassic red sandstones and shales (Dockum group) are revealed in the walls of such canyons as the Dry Cimarron and Canadian, so that the deeper underground conditions can be judged only from exposures of the upturned edges of the rocks in the front range of the Rocky Mountains. These exposures are so distant that there may be considerable change in the

character of the materials in the interval. A section measured by Lee²² not far north of the Colorado State line is as follows:

Geologic section measured on the south fork of Purgatoire River in southern Colorado.

	Feet.
Sandstone (Dakota) massive, quartzitic.....	95
Shale, fine grained, sandy, dark (Purgatoire formation).....	3
Sandstone, conglomerate (Purgatoire formation).....	50
Not exposed	50
Shale and sandstone (Morrison formation), variegated; red agates near base.....	150
Not exposed [probably gray and red sandstones and red shale— N. H. D.].....	632
Sandstone, conglomeratic with some shale (red beds); many coarse conglomerate, pebbles up to 8 inches or more in diameter, of crystalline and metamorphic rocks.....	11,537
Sandstone, dark red, more or less quartzose, much harder than the red beds above. Small pebbles and conglomerate in places....	2,508
Crystalline rocks [pre-Cambrian].	15,025

Ten miles farther north Lee found shale and limestone at the base of this series, and several limestone and dark shale members were included. As these beds are represented by limestone and dark shale in Kansas, probably in Union County a considerable amount of this material will be found when the formation is penetrated by wells. The total thickness of beds below the Morrison formation will probably prove to be less than 4,000 feet.

In the Raton coal field the Dakota sandstone is overlain by 5,000 feet or more of shale and sandstone of later Cretaceous age (Benton to Pierre) and by the Raton formation, of early Tertiary age. That the shales from the Benton to the Pierre are more than 2,500 feet thick is shown by the failure of deep holes at Raton and Vermejo Park to reach their base. A 3,000-foot hole at Raton began about 300 feet below the top of the Pierre shale and was entirely in shale, apparently not reaching the base of the formation. A hole at the Bartlett ranch, in Vermejo Park, began about 230 feet below the top of the Pierre shale and penetrated about 2,300 feet of shale, apparently all Pierre. The Niobrara and Benton shales are doubtless more than 1,000 feet thick and include two thin beds of limestone. A small amount of sandstone may also be included, possibly the equivalent of beds which carry oil in Colorado, Wyoming, and some other States. These shales are absent in Union County except for a few small thin outliers in some of the western townships and a small area at Moses. In Mora County they cap the ridge east of the Canadian Canyon and occupy a basin west of that canyon which

²² Lee, W. T., *Geology of the Raton Mesa and other regions in Colorado and New Mexico*: U. S. Geol. Survey Prof. Paper 101, p. 41, 1917.

may be 600 to 800 feet deep west of Nolan. The north end of another basin enters the county south of Golondrinas, but it does not contain more than 450 feet of the shales.

The stage of carbonization (incipient alteration) of the lower group of coals in the Raton coal field makes it appear probable that oil in commercial amounts will not be found in the Vermejo coal-bearing formation or in underlying formations near Fishers Peak and possibly not in Vermejo Park, though gas is likely to be found in the local domes and anticlines. Information is lacking as to the degree of carbonization of the carbonaceous matter of the rocks farther south toward Turkey Mountain and Las Vegas.

LOCAL STRUCTURE.

The main anticlinal fold is a broad dome elongated to the northeast and southwest, whose axis passes a short distance east of Folsom and which flattens out in the northeastern part of Mora County. To the north it extends some distance into Colorado, with relations that have been shown in a previous report.²⁴ In the highest part of the dome, near Folsom, the surface of the Dakota sandstone reaches an altitude of about 7,200 feet. From this place westward the dips are to the west at a very low angle and, as shown in figure 17, the Dakota sandstone passes under shales which at Raton are more than 3,000 feet thick.

To the southwest the shale covering decreases in thickness, owing to erosion, and the Dakota sandstone is exposed in the Canadian Valley as far north as Taylor. Near Springer it is only a few hundred feet below the surface. The sandstone comes up again in Ocate Park, apparently in a low, flat anticline, and it is sharply upturned in the Turkey Mountain dome, which reveals the "Red Beds."

The Vermejo Park anticline or dome, as shown in figures 16 and 17, rises on the west slope of the Raton coal basin. At Vermejo Park, which is on its eroded crest, the Pierre shales are exposed, and the cliffs encircling the park consist of Trinidad sandstone and overlying strata. The uplift amounts to several hundred feet.

A small uplift in the "Red Beds" under the Exeter sandstone is revealed in the canyon of the Dry Cimarron, 6 miles east of Valley. An anticline of considerable prominence extends northward across the valleys of the Dry Cimarron and Travesser Creek, in R. 32 E. During 1919 the United Oil Co. has been boring a test well on this anticline. The record to a depth of 2,725 feet is given on pages 193-194.

DEEP BORINGS.

A number of deep holes have been bored in northeastern New Mexico, mostly for water. A 2,530-foot hole at the Bartlett ranch,

²⁴ Darton, N. H., The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 661, pp. 19-21, pl. 1, 1918.

in Vermejo Park, was entirely in shale, probably all Pierre, because the Timpas and Greenhorn limestones were not reported. The Dakota sandstone may be several hundred feet below the bottom of this hole.

A 2,700-foot hole at Raton had a similar record.

It was reported in 1918 that a test hole for oil or gas had been started north of Des Moines and another one on the Dry Cimarron, in the extreme northeast corner of the State, but no reports of progress have been received. The latter hole was on or near the crest of a local anticline or dome in the "Red Beds."

At Solano, on the El Paso & Southwestern Railroad, a hole was bored to a depth of 926 feet by the railroad company for water, without success. The record showed brown sandstone to 221 feet, sand and shale from 221 to 276 feet, and hard rock and white sandstone from 276 to 307 feet, below which there is blue clay and doubtless several hundred feet of "Red Beds."

The boring of the United Oil Co. in T. 31 N., R. 33 E., has a depth of 2,725 feet. Samples of drillings to a depth of 2,337 feet were furnished by R. S. Shannon and aid somewhat in interpreting the record.

*Record of boring of United Oil Co. in NW. $\frac{1}{4}$ sec. 6, T. 31 N., R. 33 E.,
Union County, N. Mex.*

	Feet.
Sand and sandy shale, blue.....	0-68
Sandstone.....	68-108
Shale, blue or brown.....	108-159
Shale, sandy, red.....	159-179
Sandstone, coarse.....	179-193
Sandstone, red.....	193-227
Shale, red; some limestone.....	227-259
Limestone and sandstone, red.....	259-271
Shale, red, sandy.....	271-293
Limestone, red, and blue shaly sandstone.....	293-319
Shale, red, and limestone.....	319-363
Limestone.....	363-383
Limestone and red shale.....	383-400
Shale, red, sandy; some limestone near 470 feet.....	400-574
Limestone, sandy, hard.....	574-595
Shale, red, and limestone (dolomite).....	595-615
Shale, blue; some gray dolomite and sandstone.....	615-652
Sandstone, shale, and limestone.....	652-680
Sandstone.....	680-700
Sandstone and blue shale; some dolomite.....	700-720
Sandstone, mostly gray.....	720-760
Shale, blue, sandy.....	760-778
Limestone and sandstone alternating.....	778-847
Sandstone; some red sandy shale.....	847-880
Sandstone, mostly red; some limestone.....	880-945
Sandy shale, red.....	945-960

	Feet.
Sandstone, red.....	960-970
Sandy shale, red.....	970-990
Sandstone, red; some dolomite near 995 feet.....	990-1, 015
Sandy shale, red.....	1, 015-1, 053
Limestone, red, hard.....	1, 053-1, 121
Sandstone, soft.....	1, 121-1, 161
Sandstone, red, and sandy clay, red.....	1, 161-1, 205
Limestone, hard, and sandstone.....	1, 205-1, 211
Limestone, red.....	1, 211-1, 240
Sandstone, limestone, and shale, red.....	1, 240-1, 260
Sandy shale, mostly red.....	1, 260-1, 312
Sandstone, red, and limestone.....	1, 312-1, 342
Sandstone, red, hard.....	1, 342-1, 357
Sandy shale, red, and limestone.....	1, 357-1, 372
Limestone, hard.....	1, 372-1, 398
Limestone, hard, and sandstone.....	1, 398-1, 430
Sandy shale, red.....	1, 430-1, 513
Red rock, hard.....	1, 513-1, 700
Sandstone, red, coarse.....	1, 700-1, 760
Red rocks.....	1, 760-1, 960
Limestone, hard, sandy, red.....	1, 960-2, 040
Limestone, hard, sandy, white.....	2, 040-2, 080
Limestone, hard, sandy, red.....	2, 080-2, 104
Sandstone, red, soft; water.....	2, 104-2, 123
Sandstone, red, hard.....	2, 123-2, 597
Limestone, sandy.....	2, 597-2, 647
Sandstone, gray.....	2, 647-2, 654
Sandstone, pink.....	2, 654-2, 670
Sandstone, red.....	2, 670-2, 725

It is said that granite was found at the bottom.

A hole drilled for oil in the NW. $\frac{1}{4}$ sec. 32, T. 20 N., R. 31 E., penetrated red beds to a depth of about 2,200 feet. It found nothing but a strong flow of noncombustible gas.

CENTRAL EASTERN COUNTIES.

GENERAL RELATIONS.

The area comprising Guadalupe, De Baca, and Quay counties and the part of San Miguel County lying below the Canadian escarpment is mostly in the valleys of Canadian and Pecos rivers. To a large extent the strata in this area dip eastward, but the inclination is so slight that it is imperceptible to the eye. Several shallow basins and low arches or domes²⁵ have been found in this area, and it is probable that careful scrutiny will reveal others.

The general structural relations are shown in the accompanying cross section (fig. 18).

²⁵ Attention was called to some of these domes in U. S. Geol. Survey Press Bulletin 413, June 26, 1919.

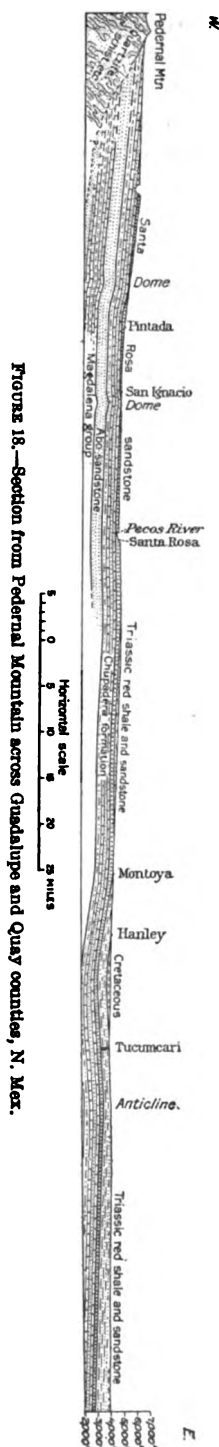
STRATIGRAPHY.

The rocks that crop out in the area are red shales and sandstones of Triassic age (Dockum group) in the lower lands and the Purgatoire and Dakota formations in the adjoining mesas. Just west of Tucumcari these sandstones descend into a structural basin and occupy its center for some distance.

The Triassic red shales and sandstones are about 800 feet thick and include near their lower part a prominent bed of gray sandstone which comes to the surface at Santa Rosa and is exposed widely in plateaus to the west, north, and south of that place. Small amounts of asphalt or dried-up petroleum occur in ledges of this sandstone on the banks of Pecos River 8 miles north-northwest of Santa Rosa, and it is possible that oil will be found in the sandstone east of this place, where it is from 50 to 550 feet below the surface. Next below this sandstone are some red shales, and then limestones, sandstones, and gypsum deposits of the Chupadera formation, which crop out in the southwestern part of Guadalupe County, the eastern part of Torrance County, and the southwestern part of San Miguel County. This formation, which is 1,000 to 1,200 feet thick, contains beds of sandstone that may yield oil in places where the structural conditions are favorable. The red sandstones of the Abo formation underlying the Chupadera formation are probably 800 feet thick and are not likely to be oil bearing. They are underlain by limestones and shales of the Magdalena group, which is 1,200 feet or more thick in the Rocky Mountain and Sandia uplifts and which lies on a floor of pre-Cambrian granite, schist, and other crystalline rocks. The 2,013-foot hole sunk in the Esterito dome, 25 miles northwest of Santa Rosa, apparently found but little if any of the Magdalena group lying on the granite.

LOCAL DOMES.

One of the most marked structural features in central eastern New Mexico is the Esterito dome (fig. 19), just east of Dilia, in the middle



of the Anton Chico grant, about 25 miles northwest of Santa Rosa. It is in a region of "Red Beds" and brings to the surface on its eroded crest the top limestone and upper sandstone of the Chupadera formation. (See section, fig. 20.) The area of exposure of these beds is only about 3 square miles. The upturned edges of the red beds crop out on the flanks of the dome. Further details of this dome are shown by figure 19, constructed from a contour map kindly furnished by Mr. J. R. Gardner, of Tulsa, Okla., based on a detailed survey by Messrs. Newby, Garrett, Crabtree, and Wright. In 1918-19 a hole was bored by the Gypsy Oil Co. in sec. 30, T. 11 N., R. 19 E., to test

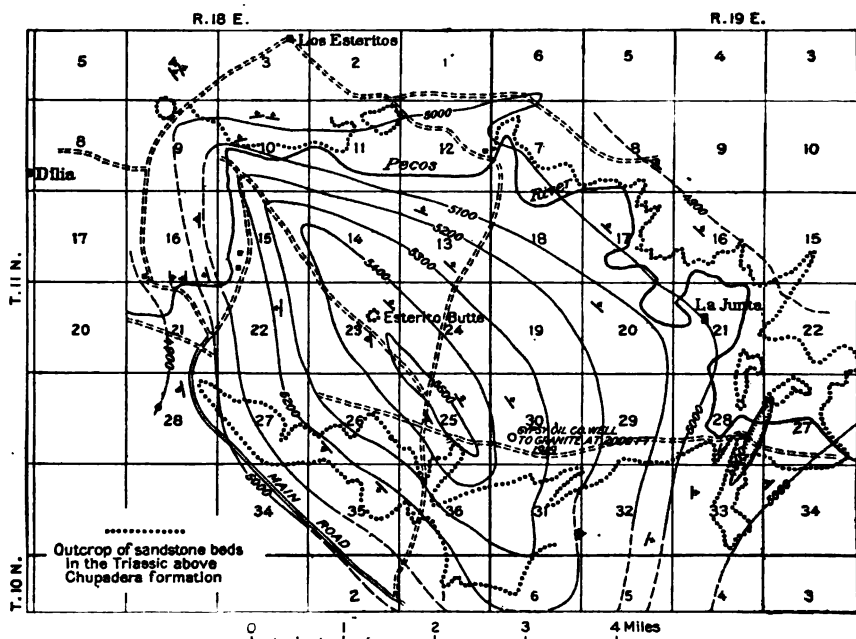
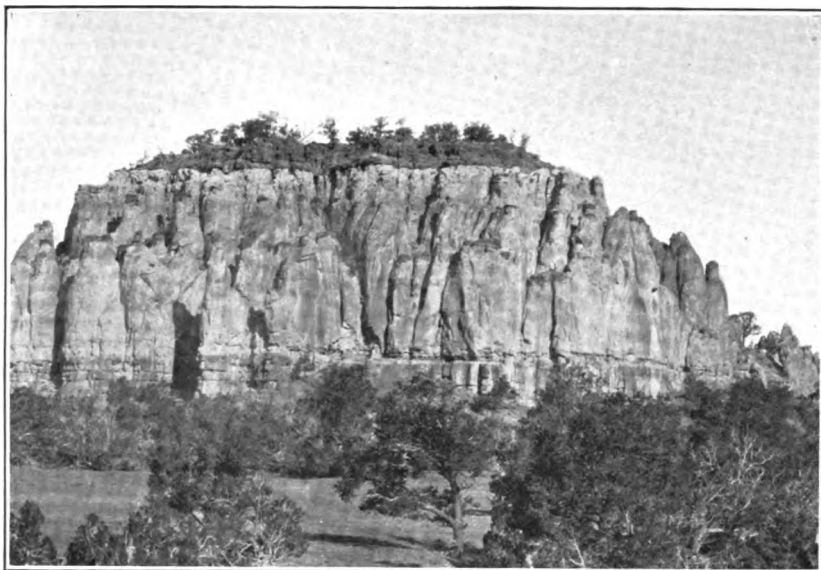


FIGURE 19.—Map of Esterito dome, Guadalupe County, N. Mex.

the resources of this dome. It was finally discontinued in granite at a depth of 2,013 feet. The strata penetrated, according to the log on pages 198-199, kindly furnished by Mr. G. C. Matson, are sandstone and limestone from the surface to probably about 1,045 feet, the Abo sandstone from 1,045 to 2,000 feet, and granite from 2,000 to 2,013 feet. The Magdalena group appears to be absent, although possibly it is represented by some of the red rocks with two thin beds of limestone between 1,575 and 2,000 feet. The character of the Chupadera formation in this region is indicated by strata below 575 or 580 feet, in the record of the 1,003-foot hole 15 miles east. (See p. 198.) Two domes of moderate prominence are indicated by outcrops of limestone of the Chupadera formation in Canyon Blanco, 10 miles southwest of Anton Chico.

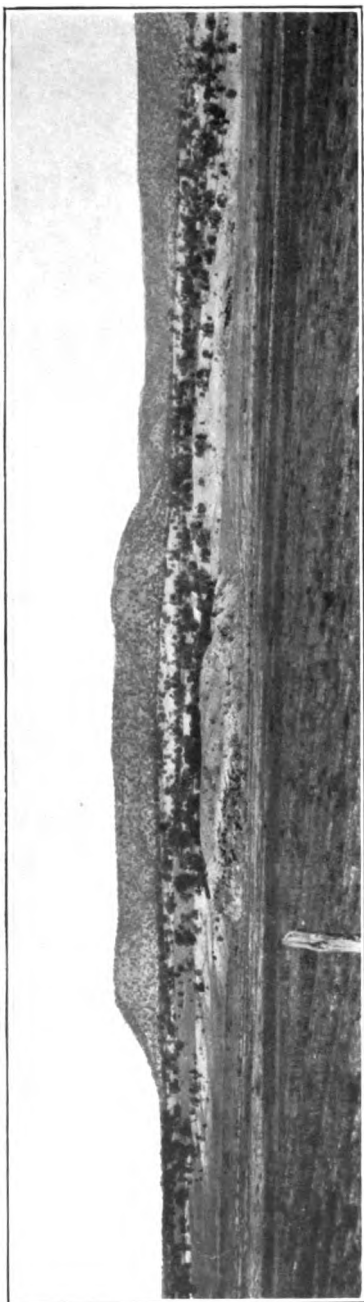


A. NAVAJO AND DAKOTA SANDSTONES AT ATARQUE, N. MEX.

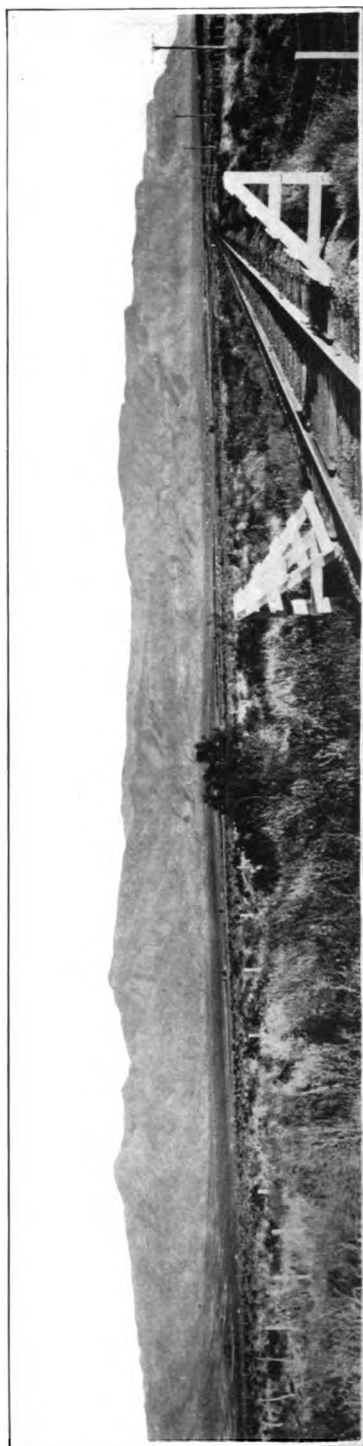
Unconformity shows just above the tree tops.



B. DAKOTA SANDSTONE AT BLUEWATER FALLS, N. MEX., LOOKING WEST.



A. DOME NEAR SAN IGNACIO, N. MEX.



B. WEST FRONT OF SACRAMENTO MOUNTAINS, N. MEX., FROM A POINT NEAR ALAMOGORDO.

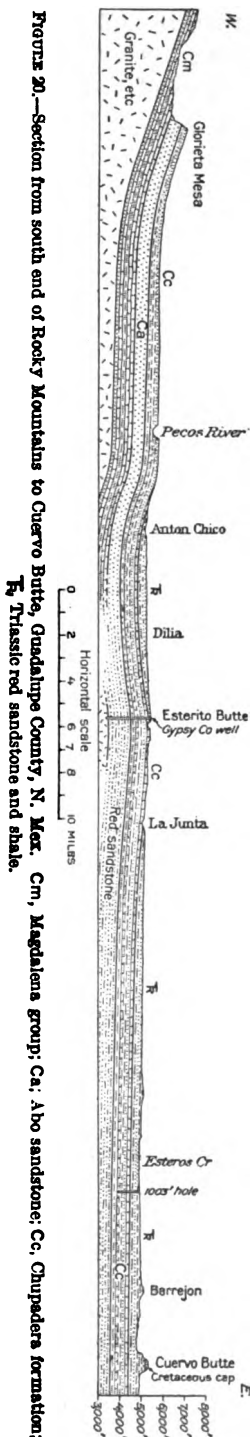
A small but well-defined dome is exhibited near the center of T. 8 N., R. 19 E., in Pintada Canyon a mile east of San Ignacio post office. It brings to the surface limestone and gypsum at the top of the Chupadera formation. The relations are shown in figure 18 and Plate XXXVI, A. Another dome appears in this canyon 3 miles above Pintada post office, but its crest is not sufficiently elevated to expose the top of the Chupadera formation, which, however, is not far below the bottom of the canyon.

There is a slight doming of the strata a short distance east of Santa Rosa and at several other places in the extensive region of red beds in the southeastern part of San Miguel County and the northeast corner of Guadalupe County. No details of the structure have been determined. A shallow synclinal basin east of Montoya extends across the western part of Quay County and the southeast corner of San Miguel County, as shown in figure 18. On the east side of this basin east of Tucumcari the strata rise on a low arch that extends some distance north up Ute Creek valley and some distance south, probably as far as the rise to the Staked Plains. In this arch the sandstones of the deeply buried Chupadera formation, probably 800 to 1,000 feet or more deep, should be tested, and possibly the underlying Abo sandstone and Magdalena group. Minor domes were observed east and south of Tucumcari.

DEEP BORINGS.

Very few deep holes have been bored to test the strata in east-central New Mexico. Several years ago a hole was bored for oil on the Perea grant, on Pecos River 7 or 8 miles above Santa Rosa, but no facts as to depth or record were obtainable. In 1916 a 1,003-foot hole was bored on the Preston Beck grant, 12 miles north-northeast of Santa Rosa. It penetrated the Chupadera formation for some distance but was not in an area of favorable

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structure and was not deep enough to test all the strata. The following record is made up from drillers' logs and my own tests of samples of the borings:

Record of boring on Beck grant, 12 miles north-northeast of Santa Rosa, N. Mex.

	Feet.
Sandstone, gray.....	0-140
Sandstone and blue shale.....	140-195
Sandstone; some water.....	195-205
Shale, blue.....	205-215
Sandstone, gray; much water at top.....	215-255
Sandstone, with limestone in lower part.....	255-345
Shale, red, sandy.....	345-380
Shale, blue, part limy.....	380-405
Shale, red, brown, and gray.....	405-425
Shale, blue, and limestone.....	425-450
Shale, red; some gray.....	450-490
Shale, blue.....	490-510
Shale, red.....	510-525
Shale, blue.....	525-535
Shale, brown to red.....	535-550
Sandstone, gray; water.....	550-560
Shale, red, on gypsum.....	560-580
Limestone, dark shale, and gypsum.....	580-680
Gypsum, anhydrite, limestone, and black shale.....	680-800
Sandstone, gray.....	800-915
Limestone and shale.....	915-935
Sandstone.....	935-955
Gypsum and limestone.....	955-975
Sandstone; some brackish water.....	975-1,003

The hole bored in 1918-19 by the Gypsy Oil Co. in the Esterito dome, in the Anton Chico grant, northwest of Santa Rosa, had the following record, supplied by Mr. G. C. Matson:

Record of hole bored by Gypsy Oil Co. in the SW $\frac{1}{4}$ sec. 30, T. 11 N., R. 19 E., Guadalupe County, N. Mex.

	Feet.
No record.....	0-187
Sandstone.....	187-380
Sandstone, dark.....	380-425
Sandstone, gray.....	425-500
Sandstone, black.....	500-520
Shale and sandstone, red.....	520-1,026
Limestone.....	1,026-1,045
Red rock.....	1,045-1,065
Sandstone; lower part white.....	1,065-1,108
Red rock.....	1,108-1,155
Sandstone.....	1,155-1,175
Shale, red.....	1,175-1,195
Shale, blue.....	1,195-1,200
Red rock.....	1,200-1,265
Sandstone; water.....	1,265-1,287
Limestone, red.....	1,287-1,299
Sandstone, red and gray, alternating.....	1,299-1,575

	Feet.
Sandstone; water.....	1, 575-1, 588
Limestone.....	1, 588-1, 600
Shale, red.....	1, 600-1, 660
Limestone.....	1, 660-1, 675
Red shale and sandstone.....	1, 675-1, 800
Red rock.....	1, 800-1, 870
Sandstone.....	1, 870-1, 990
No record.....	1, 990-2, 000
Granite.....	2, 000-2, 013

The heavy sandstone of the Chupadera formation extends to a depth of 520 feet, and doubtless some of the underlying red beds are basal members of the formation, including, perhaps, the limestone at 1,026 to 1,045 feet. The Abo sandstone may extend to the granite, or some of the lower beds from 1,588 to 2,000 feet may represent the Magdalena group, but they include only 27 feet of limestone.

A 857-foot well for water at Pastura passed through 180 feet of alternating beds of limestone and compact gypsum, 15 feet of sandstone, 25 feet of hard dark limestone, 50 feet of sandstone, 60 feet of gypsum, and 280 feet of limestone and gypsum to sandstones of light color at 520 feet, which yielded considerable hard water.

A 3,200-foot hole 5 miles south of Buchanan penetrated alternating beds of red shale and limestone with much gypsum between 200 and 600 feet, also 200 feet of salt between 2,105 and 2,460 feet.

In 1919 several borings were being made in the eastern part of the area to test the strata for oil. One known as the McGee well, in the southeast corner of sec. 27, T. 10 N., R. 31 E., about 9 miles southeast of Tucumcari, had the following record:

Log of McGee boring, in sec. 27, T. 10 N., R. 31 E., Quay County, N. Mex.

	Feet.
Sandstone, gray.....	0-30
Shale, red.....	30-470
Water sand, salty.....	470-600
Shale, red, with 10 feet of sandstone at 666 feet.....	600-760
Water sand.....	760-783
Shale, blue.....	783-796
Water sand.....	796-800
Shale, red.....	800-905
Shale, blue.....	905-940
Water sand.....	940-970
Shale, red.....	970-1, 100
Rock salt.....	1, 100-1, 135
Shale, red.....	1, 135-1, 400
Sandrock.....	1, 400-1, 430
Rock salt.....	1, 430-1, 455
Shale, red.....	1, 455-1, 625
Limestone, gray.....	1, 625-2, 000
Shale, brown.....	2, 000-2, 200

	Feet.
Limestone, dark; salt at 2,372-2,377 feet	2, 200-2, 550
Shale, brown.....	2, 550-3; 200
Limestone, black.....	3, 200-3, 220
Salt.....	3, 220-3, 225
Shale, brown.....	3, 225-3, 325
Limestone and sandstone, red.....	3, 325-3, 340
Shale, brown.....	3, 340-3, 505
Limestone, dark.....	3, 505-3, 520
Sandy shale, red.....	3, 520-3, 550
Limestone, blue.....	3, 550-3, 575
Shale, blue.....	3, 575-3, 595
Shale and lime, red.....	3, 595-3, 685
Sand, brown.....	3, 685-3, 730
Partly limy.....	3, 730-3, 820
Shale, blue.....	3, 820-3, 825
"Red lime with granitic sand".....	3, 825-3, 854
Limestone, black.....	3, 854-3, 859
Shale, blue.....	3, 859-3, 869
Limestone, gray to brown.....	3, 869-3, 953
Shale.....	3, 953-3, 958
Limestone, brown.....	3, 958-4, 014

A hole in sec. 7, T. 11 N., R. 36 E., was in progress in 1920. Blue shale was the prevailing material to 1,500 feet and limestone from 1,500 feet to 2,300 feet; red shale was entered at about 2,500 feet. A hole in sec. 25, T. 13 N., R. 32 E., on Canadian River 15 miles north-east of Tucumcari, had reached a depth of 1,210 feet. Sandstones and red shales predominate to a depth of 905 feet, below which are gray limestones with a few beds of brown and gray shale.

ROCKY MOUNTAINS.

The great uplift of the Rocky Mountains extends far southward into New Mexico as a series of high ridges consisting largely of granite, schist, and other crystalline rocks of pre-Cambrian age, overlain by limestones and sandstones of Carboniferous age. The range is relatively narrow, having a width of about 25 miles in Taos County and 35 miles east of Santa Fe. The principal structural feature is an anticline or series of anticlines. Two typical sections are given in figure 21.

Many of the details of the structure of the Rocky Mountains in New Mexico have not been determined, especially the relations of the faults and minor flexures. The uplift pitches steeply toward the south, and the crystalline rocks and limestone pass underground in the vicinity of latitude $35^{\circ} 30'$, or near the line of the Santa Fe Railway. The prolongations of the anticlines, however, are traceable for some distance farther south in the Glorieta and other mesas in the southwestern part of San Miguel County and the southeastern part of Santa Fe County, described on page 202. The principal sedimentary rocks in the Rocky Mountain uplift are those of the Magda-

lena group, which consists of limestones and sandstones, the latter predominating in the upper and later portions of the formation. These rocks arch over most of the higher parts of the range, but in some areas they have been removed by erosion and the underlying granites, schists, etc., are revealed. These limestones and sandstones, lying high on the mountain slopes, with so little cover, are not likely to contain oil or gas.

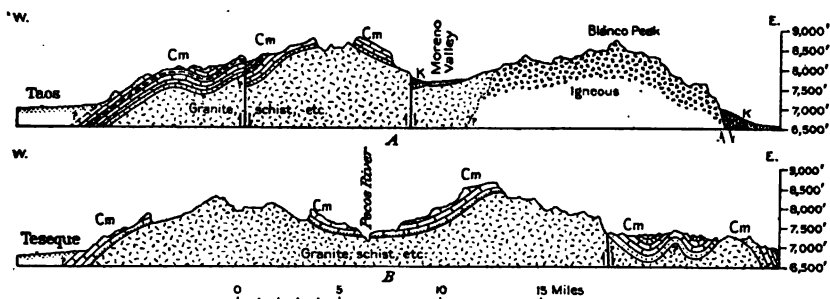


FIGURE 21.—Generalized sections across the Rocky Mountains in New Mexico. *A*, From Taos eastward; *B*, eastward from a point 6 miles north of Santa Fe. Cm, Magdalena group; K, Cretaceous sandstone and shale.

EAST-CENTRAL PLATEAU REGION.

GENERAL RELATIONS.

The east-central plateau region comprises the southeastern part of Santa Clara County, the western part of San Miguel County, and the eastern part of Torrance County. From the south end of the Rocky Mountains there extends southward a broad plateau which in the northern part of Lincoln County merges into the Sacramento Cuesta and in the southern part of Torrance County merges into the Chupadera Mesa. Glorieta Mesa is at the north end of the plateau, and it slopes eastward into the valley of Pecos River. The surface is sandstone to the north and limestone to the south, but from Pedernal Mountain to Pinos Wells the pre-Cambrian crystalline rocks appear, in places rising considerably above the general level.

STRATIGRAPHY.

The sedimentary strata underlying the east-central plateau region are shown in the following table:

Formations in the east-central plateau region of New Mexico.

Formation.	Characteristics.	Thickness (feet).
Chupadera formation.	Massive gray sandstone to north; alternating limestone, gray sandstone, gypsum, and soft red sandstone to south.	1,000-1,100
Abo sandstone.	Brown-red sandstone and red sandy shale; some gray sandstone.	700-800
Magdalena group.	Largely limestone, with alternations of limestone, sandstone, and shale in lower part.	1,100-1,200
Granite, schist, etc.	With thick mass of gray quartzite in Pedernal region.	

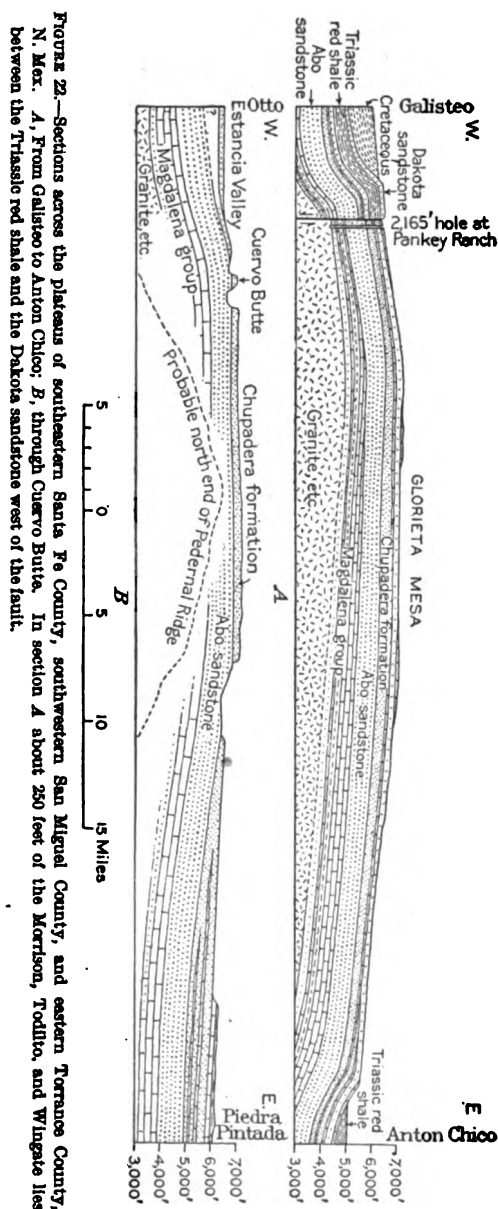
The strata most favorable for oil or gas, if these materials are present, are the sandstones included in the Magdalena group, which lie at a depth of about 2,000 feet in most parts of the plateau area. Possibly some

of the coarser, more porous sandstones of the Abo may also be favorable, but the sandstone of the Chupadera formation apparently has little cover, some of the canyons cutting into or through it. The Magdalena group and Abo sandstone are absent in an area of considerable extent adjoining Pedernal Mountain and the associated quartzite ridges, which probably continue underground as far north as T. 10 N.

LOCAL STRUCTURE.

The main structural feature of this district is an anticline or a southward prolongation of part of the Rocky Mountain uplift, with a low dip to the east and steeper dips on the west, notably in the region east of Lamy. The sections in figure 22 show the chief structural features.

The strata dip down under Estancia Valley and the Galisteo Basin, where the Chupadera is overlain by later formations. To the east, in the southwestern part of San Miguel County, the larger valleys cut through to the underlying red Abo sandstone. Toward the south the pre-Cambrian quartzite of the



Pedernal region rises as an old ridge in the midst of the later Carboniferous sediments. How far north this quartzite extends is not known, but it may constitute the center of the uplift for some distance north of Pedernal Mountain, cutting out the lower formations.

DEEP BORINGS.

The most notable deep boring in this region is one sunk in 1918 for oil and gas near the Pankey ranch, on the Eaton grant, south of Lamy. The following record of the hole was kindly supplied by the Toltec Co., which made the boring:

Record of hole on Eaton ranch, 7 miles south of Lamy, N. Mex., approximately in sec. 2, T. 15 N., R. 10 E.

	Feet.
Sandstone, buff, coarse.....	0-40
Shale, blue, gritty.....	40-100
Sandstone.....	100-150
Shale.....	150-165
Sandstone, chocolate-colored.....	165-185
Shale, chocolate-colored.....	185-215
Limestone, dolomitic, fine grained.....	215-250
Shale, sandy, chocolate-colored to red.....	250-300
Sandstone, fine, white.....	300-360
Gypsum (?), white, sandy.....	360-400
Limestone, gray, and sandstone.....	400-580
Sandstone, fine, gray.....	580-600
Gypsum, limestone, and shale.....	600-630
Sandstone, white.....	630-640
Shale, sandy, chocolate-brown.....	640-775
Sandstone, white.....	775-780
Shale, red.....	780-820
Shale, chocolate-colored.....	820-880
Shale, sandy, limy.....	880-890
Sandstone, fine, white.....	890-940
Shale, blue.....	940-1,003
Shale, chocolate-colored, sandy.....	1,003-1,035
Sandstone, red.....	1,035-1,070
Shale, chocolate-colored; some sand.....	1,070-1,100
Sandstone, fine, light red.....	1,100-1,150
Shale, greenish.....	1,150-1,200
Shale, with some sand, chocolate-colored at top.....	1,200-1,300
Shale, sandy and limy.....	1,300-1,400
Limestone, gritty (?).....	1,400-1,455
Shale, limy to sandy, chocolate-colored.....	1,455-1,590
Shale, more sandy.....	1,590-1,640
Sandstone, red, and chocolate-colored shale.....	1,640-1,715
Conglomerate.....	1,715-1,720
Shale, dark; some sandy.....	1,720-1,865
Limestone, blue.....	1,865-1,920
Limestone, dark gray.....	1,920-1,980
Sandstone, dark red.....	1,980-1,994
Schist and quartzite (probably pre-Cambrian).....	1,994-2,165

Samples of the materials from various depths were furnished and tested in the laboratory of the United States Geological Survey. The sample at 1,895 feet was limestone, those at 1,910, 1,930, and 1,950 feet calcareous shale, at 1,994 feet quartz, at 2,012 feet schist,

at 2,080 feet quartzitic schist, at 2,090 feet quartz, and at 2,150 feet schist.

The record does not give the characteristics of all the beds penetrated, so that the position of the Chupadera formation is not apparent, but the base of the Abo appears to have been reached at 1,400 feet, below which to 1,950 feet the boring was in the Magdalena group. A conglomerate with granite fragments from 1,720. to 1,725 feet was a notable feature. The material from 1,994 feet to the bottom appears to be quartzite and schist of pre-Cambrian age, the bedrock basement. As shown in section A, figure 22, the hole is in a monocline just east of a large fault, and the structural conditions are not favorable for oil or gas.

The State well in sec. 8, T. 8 N., R. 13 E., about 6 miles north of Pedernal Mountain, had the following record:

Record of well in sec. 8, T. 8 N., R. 13 E., Torrance County, N. Mex.

	Feet.
Clay, yellow.....	0-14
Limestone.....	14-29
Sandstone, yellow.....	29-90
Sandstone, red, with shale beds.....	90-160
Limestone and gypsum.....	160-170
Sandstone, yellow.....	170-180
Sandstone, red, with thin beds of shale.....	180-590
Shale, hard, blue.....	590-598
Limestone.....	598-608
Shale, hard, blue.....	608-645
Sandstone, hard, white.....	645-655
Limestone, blue.....	655-670

A 528-foot boring in sec. 8, T. 8 N., R. 14 E., about 2 miles southwest of Palma post office, in Torrance County, had the following record:

Record of State well No. 2, in sec. 8, T. 8 N., R. 14 E., Torrance County, N. Mex.

	Feet.
Limestone (?) and yellow clay.....	0-30
Limestone and gypsum (?).....	30-90
Sandstone, yellow.....	90-470
Sandstone, red.....	470-480
Sandstone, cream-colored.....	480-524
Shale, yellow to reddish.....	524-528

This well evidently was in the Chupadera formation throughout.

A 615-foot boring for water in sec. 2, T. 2 N., R. 16 E., had the following record:

Record of boring in sec. 2, T. 2 N., R. 16 E.

	Feet.
Soil and clay.....	0-60
Limestone.....	60-140
Limestone and gypsum.....	140-210
Sandstone.....	210-290
Limestone.....	290-300
Sandstone.....	300-360
Gypsum.....	360-380
Sandstone, soft from 410 to 420 feet; some water at 575 feet, 20 gallons at 612 feet; hard water.....	380-615

A deep hole sunk for water by the Atchison, Topeka & Santa Fe Railway Co. at Chapelle had the following record:

Record of well of Atchison, Topeka & Santa Fe Railway Co. at Chapelle.

	Feet.
Loam.....	0-52
Sandstone, brown.....	52-56
Sandstone, gray.....	56-72
Sandstone, white.....	72-82
Sandstone, yellow.....	82-122
Sandstone, alternating white and yellow.....	122-340
Limestone.....	340-345
Sandstone, white.....	345-350
Sandstone, red.....	350-355
Limestone.....	355-385
Not given.....	385-460
Conglomerate, sandy.....	460-465
Shale and sandstone, red.....	465-605
Sandstone, red.....	605-897
Sandstone, red, with some white.....	897-960

The sandstones of the Chupadera formation extended to a depth of 350 feet or possibly to 465 feet, where characteristic red strata of the Abo sandstone were encountered. The hole was discontinued in this formation, probably about 300 feet above the top of the Magdalena beds.

A 350-foot well at Lucy passed through 125 feet of gravel to a thin bed of hard white sandstone. Below this were alternating red shale and gray limestone of the lower part of the Chupadera formation. At Pedernal Siding the white marl (80 feet) and conglomerate (40 feet) of the valley fill were found to be underlain by 70 feet of red shale with limestone beds (Chupadera formation), lying on granite, which was penetrated from 190 to 270 feet. At Negra a 500-foot boring was in mica schist and quartzite below 150 feet. The overlying beds were red shale and red sandstone, including a 10-foot bed of limestone at 110 feet.

ESTANCIA VALLEY.

The Estancia Valley is a wide, flat-bottomed basin occupying the central part of Torrance County and most of the southern part of Santa Fe County. Its length from north to south is about 50 miles, and its average width about 25 miles. Many data relating to the geology of this area are given in a report by Meinzer.²⁸ The greater part of the surface is covered by sand and gravel several hundred feet thick, which hide the structural relations. In general the strata lie in a monocline that dips at low angles to the east, but along the east side some of the strata rise again with westerly dip on the flank of the anticline of the southern prolongation of the Rocky Mountain. (See fig. 22, p. 202.) To the south there appear in the axis of this ridge extensive exposures of pre-Cambrian quartzite constituting Pedernal Mountain and the Hills of Pedernal, and farther south, in the vicinity of Lucia and Rattlesnake Hill, schists are exposed. On the west side of Estancia Valley are long slopes of eastward-dipping limestones of the Magdalena group, which in the vicinity of Manzano and Punta pass under red sandstones of the Abo formation. (See fig. 26, p. 219.) To the south is a high wall of the Jumanes Mesa, at the north end of the Chupadera Mesa, consisting of red beds overlain by limestone of the Chupadera formation. In the slopes of the Galisteo Basin just north of Estancia Valley are exposures of Cretaceous rocks, mostly the Mancos shale, which doubtless extend for some distance southward, possibly as far as Stanley or Otto. Cerrito del Lobo is an outlying mass of pre-Cambrian quartzite, and it is stated that this rock was found in the SE. $\frac{1}{4}$ sec. 17, T. 6 N., R. 12 E., at a depth of 40 feet and in the SE. $\frac{1}{4}$ sec. 32, T. 5 N., R. 11 E., at a depth of 145 feet. A well 232 feet deep in the NE. $\frac{1}{4}$ sec. 14, T. 7 N., R. 11 E., did not find quartzite. It is evident from these facts that under the center of the southern part of Estancia Valley there is an overlap of the later Carboniferous rocks on the slope of an old ridge of quartzite, which reaches the present surface in the Hills of Pedernal.

Many shallow wells have been sunk for water in Estancia Valley, but no suitable tests have been made for petroleum, and although the prospects, structural or stratigraphic, appear not to be promising, still it is possible that oil might be found in the Magdalena group in the west half of the valley. Owing, however, to the cover of superficial materials the structural relations are hidden in the greater part of this region. In the area to the west where the limestone constitutes the surface there are several domes and anticlines, notably in the ridges east of Chilili, but the structure of these features

²⁸ Meinzer, O. E., *Geology and water resources of Estancia Valley, N. Mex.*: U. S. Geol. Survey Water Supply Paper 275, 1911.

has not been unraveled in detail. The Magdalena group appears to be about 1,200 feet thick, and though it consists mainly of limestone, it includes several beds of sandstone, notably in its lower portion.

SACRAMENTO CUESTA.

GENERAL RELATIONS.

The Sacramento Mountains form the highly elevated portion of the western margin of the great limestone cuesta that extends from the east side of the Tularosa Basin to the Pecos Valley. (See Pl. XXXVI, *B*, p. 197.) This cuesta attains an altitude of more than 9,000 feet south of Cloudcroft and slopes down on the east to an altitude of about 3,200 feet in the Pecos Valley in Eddy County. To the south the high cuesta continues into the Guadalupe Mountains, which extend to the southern margin of New Mexico and to El Capitan Peak, in Texas, where the altitude is 8,690 feet. The principal structural features of this region are shown in the cross sections in figure 23. In the northwestern portion of the region there is a deep basin of Cretaceous and overlying igneous rocks, and to the north, in Capitan Mountain, the strata are cut by a large mass of later Tertiary intrusive rock. In the greater part of the region there is a general uniform dip to the east, with a few local variations and some faults. The details of structure in this region have not yet been investigated, and it is probable that when detailed surveys are made domes, anticlines, and terraces will be found on the monocline.

STRATIGRAPHY.

The rocks underlying this cuesta consist of a thick mass of the Chupadera formation, the red Abo sandstone, and 2,500 feet or more of limestones, shales, and sandstones of the Magdalena group and older formations. It appears probable that this succession includes some beds that may be favorable as sources or reservoirs of oil or gas, especially toward the east. Moreover, it is in the Chupadera formation that the oil at Dayton occurs; and although the pool in that place appears to be of small area it is not unlikely that the conditions of occurrence may be duplicated, possibly on a much larger scale, in other portions of the region. To the west the higher sandstones of the Chupadera formation are deeply trenched by the stream valleys, but to the east they pass under cover and storage conditions may be more favorable. Probably in the underlying red beds of the lower half of the Chupadera formation and in the 500 to 1,000 feet of sandstones that constitute the Abo formation the prospects for oil are very poor. On account of the more favorable composition of the beds the prospects may be better in the sandstone of the underlying Magdalena group, which are from 2,000 to 3,000 feet below the surface in this region.

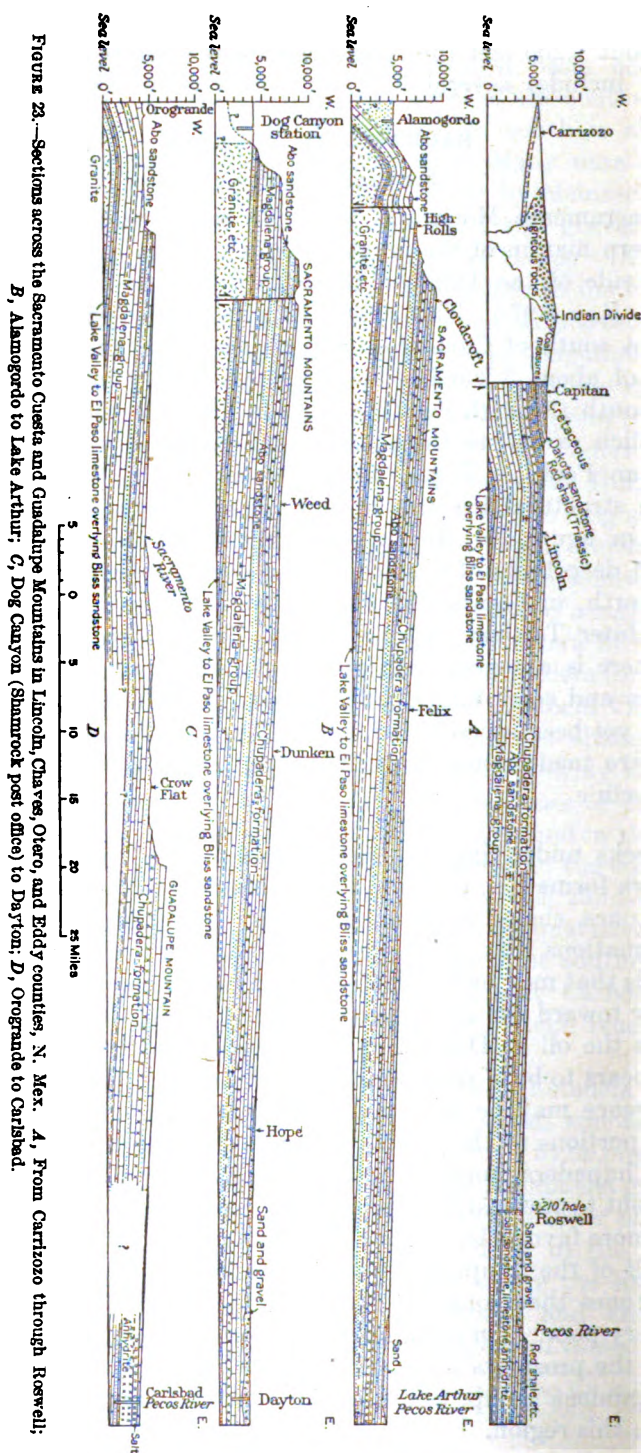


FIGURE 23.—Sections across the Sacramento Cuesta and Guadalupe Mountains in Lincoln, Chaves, Otero, and Eddy counties, N. Mex. A, From Carrizozo through Roswell; B, Alamogordo to Lake Arthur; C, Dog Canyon (Shamrock post office) to Dayton; D, Orogrande to Carlsbad.

LOCAL STRUCTURE.

The Sacramento Mountains are due mainly to an anticlinal uplift which in the higher portion of the range for a few miles southeast of Alamogordo is probably broken by a fault. North of Alamogordo, as shown in section *B*, figure 23, the arch is complete, at least in the Magdalena group, and southeast of Alamogordo the uplift is well exposed in Alamo Creek. The arch rises so high in Agua Chiquita Canyon that the pre-Cambrian granites appear for a short distance in the west foot of the mountain. A fault passes into the mountain front 4 miles southeast of Alamogordo. At La Luz the westerly dips are pronounced. Anticlinal structure appears again to the south in and south of T. 20 N., as shown in section *D*, figure 23, and the fold is well marked east and southeast of Orogrande, where it finally continues into the Hueco Mountains in Texas. (See also section *F* in fig. 28.) Just west of High Rolls there is a second anticline, whose western limb is steeply upturned and somewhat faulted. The

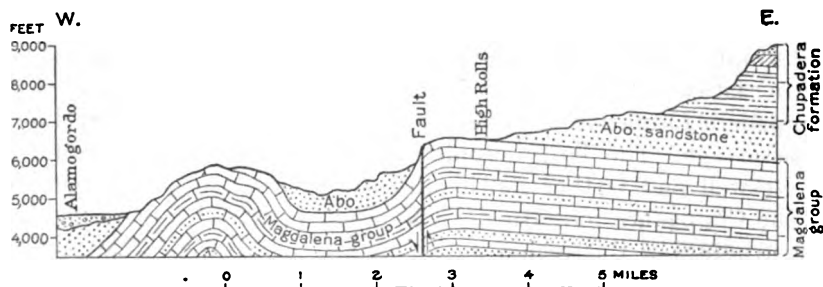


FIGURE 24.—Sketch section of anticlines and fault between Alamogordo and High Rolls, N. Mex.

Magdalena group appears in both anticlines at this place, with an intervening basin of the Abo sandstone, as shown in figure 24.

In the broad cuestas on the east slope of the Sacramento Mountains there are local deviations from the uniform eastward dip, notably below Elk, where a small anticline appears. Domes are reported near Tinnie and Picacho. In the southern extension of the range there are many undulations of the strata, notably between Sacramento River and Crow Flat, where the limestones of the Chupadera formation are somewhat flexed, as indicated in section *D*, figure 23.

In the northwestern extension of the Sacramento Cuesta in Lincoln County the strata bend down into a basin which is occupied by an extensive area of Cretaceous shales and sandstones and Tertiary igneous rocks of the Sierra Blanca. East of this basin is an anticline of considerable prominence, which, as shown in section *A*, figure 23, passes a short distance west of Lincoln. Its axis is in the outcrop of the Chupadera formation, which is underlain by the Abo sandstone and Magdalena group in regular order. This uplift passes northward through the Jicarilla Mountains and dies out in the plateaus northeast

of Ancho. A minor dome on its east slope has its crest near the center of T. 7 S., R. 16 E., not far east of the Block ranch (Richardson post office). In places along the slopes near Lincoln the lower shaly and gypsiferous beds of the Chupadera formation are considerably crumpled, presenting numerous arches and basins. This deformation is due mainly to the great intrusive mass of Capitan Mountain, not far north. The more massive upper beds are not much affected.

BORING.

A 2,199-foot hole in sec. 21, T. 11 S., R. 18 E., near Picacho, penetrated shale with thin beds of limestone and gypsum at 113 to 445 feet, red clay and gypsum at 445 to 530 feet, limestone (mostly) at 530 to 770 feet, sandstone at 770 to 921 feet, red clay at 921 to 968 feet, limestone, shale, and sandstone at 968 to 1,670 feet, including 35 feet of rock salt at 1,109 feet, and granite at 1,670 to 2,199 feet.

PECOS VALLEY IN CHAVES AND EDDY COUNTIES.

GENERAL RELATIONS.

As stated above, the cuesta of the Sacramento Mountains slopes down eastward to the Pecos Valley, east of which the limestones of the Chupadera formation are overlain by red shales of probably Lower Triassic age. The large supplies of underground water obtained at Roswell and farther south originate in the sandstones included in the Chupadera formation. The cross sections in figure 23 show the structure of this region in the vicinity of Roswell, Lake Arthur, Dayton, and Carlsbad and indicate the general structure of a large part of the valley. The predominating feature is a monocline dipping eastward at a very low angle, which east of Pecos River carries the Chupadera formation to a moderate depth.

STRATIGRAPHY.

The surface rocks in the Pecos Valley in Chaves and Eddy counties are limestones, red shales, and gypsum beds at the top of and overlying the Chupadera formation. North of Lakewood there is a broad cover of sand and gravel, especially on the west side of the valley. Several deep borings show the character of the rocks underground to a considerable depth. The records of some of these holes are given on pages 212-215.

It will be seen from these records that the region is underlain by a thick succession of limestone, sandstone, anhydrite, and gypsum, including thick deposits of salt.^{26a} It is probable that none of these borings reached the base of the Chupadera formation, which therefore has a thickness of more than 3,000 feet under the Pecos Valley.

^{26a} For further information regarding the salt deposits and associated strata see Darton, N. H., Permian salt deposits of the south-central United States: U. S. Geol. Survey Bull. 715, pp. 205-223, 1921.

Next below the Chupadera are the red sandstones of the Abo formation, probably at least 700 feet thick, and then the limestones and sandstones of the Magdalena group, 2,500 feet thick, which may either extend to the pre-Cambrian basement or be separated from the crystalline rocks by older limestones and shales.

East of Pecos River there is a long irregular upgrade to the foot of the Llano Estacado. This slope consists of red beds overlying the Chupadera formation and in general having the same low dip toward the east. The rocks are mainly red shales and sandstones, with beds of limestone and gypsum not unlike those constituting part of the Chupadera formation. The total thickness of this series of deposits from the east bank of the river to the foot of the rise to the Llano Estacado is between 600 and 700 feet. A boring 25 miles east of Roswell penetrated the lower half of the series and then continued deeply into the Chupadera formation. The record given on pages 214-215 shows the beds penetrated.

LOCAL STRUCTURE.

The Pecos Valley in Chaves and Eddy counties is in general an eastward-dipping monocline, in which the dips at most places are very low. No special scrutiny was given to the details of structure, and probably there are minor domes and anticlines which might possibly present favorable conditions for the accumulation of oil or gas. A short distance southwest of Roswell there appears to be a feature of this sort, and others occur west and northwest of Carlsbad. In much of the area along the river and extending far up the slopes to the west there is a mantle of sand and gravel which hides the rocks, so that the structure can not be determined by observations at the surface.

OIL.

The only occurrence of oil in notable amount in the Pecos Valley in New Mexico is in a few wells near Dayton.²⁷ These wells are in secs. 25, 15, and 26, T. 18 S., R. 26 E. The largest yield of petroleum reported came from the Brown well, sunk in 1909 to a depth of 950 feet. The amount which this well was capable of producing was reported to be about 25 barrels a day between 911 and 926 feet. Small quantities of gas and oil were obtained from the Belt well, in the NW. $\frac{1}{4}$ sec. 25, about 1,000 feet deep, and considerable gas was struck in the Platt well, in the SW. $\frac{1}{4}$ sec. 26, at a depth of 869 feet. These wells were all in a sand-covered plain, and no information could be obtained as to the structural conditions. A number of test borings sunk in the same vicinity failed to obtain oil. Whether the failure was due to unfavorable structure or to the small extent of the oil-bearing sands could not be ascertained. The

²⁷ Richardson, G. B., Petroleum near Dayton, N. Mex.: U. S. Geol. Survey Bull. 541, pp. 22-27, 1914.

beds are in the Chupadera formation, and they underlie a wide area of the Pecos Valley at about the same depth as in the wells that yield oil. It is not unlikely that these beds will be found to contain oil at other localities, especially if favorable structure exists.

In testing for oil in Pecos Valley it is desirable not only to penetrate all the beds of the Chupadera formation but if no oil is found to sink through the Abo sandstone into sandstones of the Magdalena group. Unfortunately, however, the Magdalena beds lie at a depth approaching 5,000 feet, which will make the cost of test wells rather too high to undertake unless favorable structure can be found.

DEEP BORINGS.

The deep boring 13 miles northeast of Roswell was undoubtedly in the Chupadera formation throughout. Probably, however, the top of the Abo sandstone was not far below its bottom. The following record was kindly furnished by the Toltec Co.

Record of boring in sec. 31, T. 8 S., R. 24 E., 13 miles north-northeast of Roswell, N. Mex.

	Feet.
Dolomite.....	0-90
Sandstone on dolomite.....	90-110
Gypsum and dolomite.....	110-140
Limestone.....	140-165
Dolomite.....	165-250
Limestone and dolomite.....	250-390
Sandstone.....	390-396
Limestone; some sandstone at 518-600 feet.....	396-620
Limestone and dolomite.....	620-710
Sandstone.....	710-770
Dolomite.....	770-860
Shale, dark.....	860-864
Sandstone, red and pink.....	864-1,033
Salt on dark shale.....	1,033-1,052
Gypsum.....	1,052-1,067
Dolomite.....	1,067-1,076
Anhydrite.....	1,076-1,123
Dolomite on thin gypsum.....	1,123-1,168
Salt.....	1,168-1,200
Gypsum.....	1,200-1,230
Dolomite.....	1,230-1,280
Shale, dark.....	1,280-1,295
Dolomite.....	1,295-1,318
Shale, red.....	1,318-1,349
Dolomite.....	1,349-1,366
Sandstone.....	1,366-1,380
Anhydrite.....	1,380-1,386
Salt.....	1,386-1,449
Sandstone, red, with 15 feet of gypsum.....	1,449-1,504
Salt.....	1,504-1,565
Dolomite on shale.....	1,565-1,582

	Feet.
Sandstone, red.....	1, 582-1, 620
Salt.....	1, 620-1, 645
Dolomite, gray to brown.....	1, 645-1, 730
Sandstone, red.....	1, 730-1, 771
Salt.....	1, 771-1, 800
Anhydrite.....	1, 800-1, 858
Dolomite.....	1, 858-1, 906
Salt.....	1, 906-2, 010
Shale, gray.....	2, 010-2, 025
Salt.....	2, 025-2, 050
Dolomite, with two beds of gypsum.....	2, 050-2, 154
Salt.....	2, 154-2, 205
Dolomite on sandstone.....	2, 205-2, 268
Salt.....	2, 268-2, 310
Dolomite.....	2, 310-2, 317
Anhydrite.....	2, 317-2, 335
Dolomite.....	2, 335-2, 375
Gypsum.....	2, 375-2, 435
Salt.....	2, 435-2, 455
Sandstone, red, on pink shale.....	2, 455-2, 507
Dolomite on red sandy clay.....	2, 507-2, 530
Shale, dark, and dolomite.....	2, 530-2, 548
Sandstone, red.....	2, 548-2, 625
Gypsum.....	2, 625-2, 685
Salt.....	2, 685-2, 710
Anhydrite, 9 feet, on dolomite.....	2, 710-2, 730
Sandstone.....	2, 730-2, 740
Salt.....	2, 740-2, 750
Anhydrite.....	2, 750-2, 770
Sandstone, red.....	2, 770-2, 800
Anhydrite.....	2, 800-2, 805
Dolomite.....	2, 805-2, 830
Salt.....	2, 830-2, 860
Gypsum.....	2, 860-2, 950
Dolomite.....	2, 950-2, 971
Gypsum and sandy clay.....	2, 971-3, 025
Sandstone, red, dolomitic below 3,063 feet.....	3, 025-3, 120

The following record of a deep boring for oil near Carlsbad shows a great thickness of salt and anhydrite in the Chupadera formation:

Record of boring in the NE. $\frac{1}{4}$ sec. 4, T. 22 S., R. 28 E., near Carlsbad, N. Mex.

	Feet.
Gypsum.....	0-14
Sand, red.....	14-120
Limestone, soft.....	120-175
Clay, light, sandy.....	175-300
Anhydrite.....	300-485
Salt.....	485-618
Anhydrite.....	618-650
Salt.....	650-1, 118
Anhydrite.....	1, 118-2, 380
Limestone and anhydrite.....	2, 380-2, 490
Sandstone, hard.....	2, 490-2, 500

	Feet.
Limestone.....	2, 500-2, 555
Sandstone.....	2, 555-2, 630
Limestone.....	2, 630-2, 700
Sandstone, mostly fine.....	2, 700-2, 810
Limestone.....	2, 810-2, 820

Record of boring of Dayton Petroleum Co., in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 23, T. 18 S., R. 26 E.

	(April, 1913.)	Feet.
Sand and gravel.....		0-25
Gypsum.....		25-65
Shale, blue to gray.....		65-350
Sand.....		350-355
Shale, gray.....		355-434
Sandstone, hard.....		434-436
Shale, blue, on gravel and sand.....		436-468
Gypsum.....		468-482
"Concrete".....		482-488
Shale, gray and blue.....		488-630
Red sand on red sandy shale.....		630-685
Clay and red sand.....		685-699
Hard rock.....		699-715
Red sand and shale.....		715-750
Limestone, some soft, and red shale.....		750-879
Gypsum.....		879-894
Limestone and red shale; "oil at 930-935 feet".....		894-957
Limestone, with 5 feet of white sand.....		957-1, 126

Record of boring on Arroyo ranch of Southspring Ranch & Cattle Co., in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 5, T. 11 S., R. 28 E., Chaves County, about 25 miles east of Roswell.

	Feet.
Clay, sand, and gravel.....	0-75
Sandstone, red.....	75-150
Sandstone, red, and shale.....	150-300
Red rock and "lime shells"; gas at 435 and 460 feet.....	300-600
Shale, pink, and "lime shells".....	600-640
Shale, red.....	640-700
Limestone, hard.....	700-710
Red rock and "lime shells".....	710-750
Pink rock.....	750-800
Sandstone, red, limestone, and 2 feet of salt.....	800-850
Pink rock.....	850-900
Limestone, white.....	900-915
Pink and red rocks.....	915-990
Sandstone, red.....	990-1, 010
Red rocks and white limestone.....	1, 010-1, 125
"Lime shell" and red sandrock.....	1, 125-1, 140
Sandstone, red, and shale.....	1, 140-1, 350
Sandstone, red, with "lime shells".....	1, 350-1, 400
Shale, red.....	1, 400-1, 450
Sand, red and gray.....	1, 450-1, 485
Sand, red, and white limestone.....	1, 485-1, 540
Limestone and pink rock.....	1, 540-1, 625
Limestone, light and dark.....	1, 625-2, 098
Sand, brown, "showing of oil".....	2, 098-2, 118
Limestone, sandy, brown.....	2, 118-2, 150

	Feet.
Limestone, light and dark.....	2, 150-2, 756
Pebbly sand, white, with 4 feet of red sandstone.....	2, 756-2, 800
Limestone, light and dark.....	2, 800-2, 850
Clay and blue shale.....	2, 850-2, 943

Record of Tannehill well, 7 miles northeast of Roswell, N. Mex.

	Feet.
Gypsum and clay.....	0-60
White sand.....	60-140
Clay and gypsum.....	140-280
Red sand.....	280-330
Clay.....	330-340
Water rock.....	340-390
Limerock.....	390-410
Red cave.....	410-415
Water rock.....	415-510
Loose clay rock.....	510-565
Black lime.....	565-620
Water rock.....	620-650
Black lime.....	650-740
White lime.....	740-775
Sandstone.....	775-810
White lime.....	810-850
Black lime.....	850-900
Gray and white lime.....	900-1, 050
Sandstone.....	1, 050-1, 175
Limestone.....	1, 175-1, 205
Shells and mud.....	1, 205-1, 360
Limerock and salt.....	1, 360-1, 385
Red rock.....	1, 385-1, 405
Limestone.....	1, 405-1, 510
Blue shale.....	1, 510-1, 520
Limestone.....	1, 520-1, 600
Mud and lime shells.....	1, 600-1, 670
Limestone.....	1, 670-1, 805
Red mud.....	1, 805-1, 850
Limestone.....	1, 850-1, 925
Salt.....	1, 925-1, 940
Blue lime.....	1, 940-1, 970
Black lime.....	1, 970-2, 005
Blue shale.....	2, 005-2, 008
Limestone.....	2, 008-2, 030
Blue shale.....	2, 030-2, 037
Black lime.....	2, 037-2, 060
Shale.....	2, 060-2, 080

Late in 1920 borings were in progress at the following places in Pecos Valley in Chaves and Eddy counties:

- SE. $\frac{1}{4}$ sec. 15, T. 12 S., R. 25 E., 10 miles southeast of Roswell.
- SW. $\frac{1}{4}$ sec. 15, T. 15 S., R. 26 E., $2\frac{1}{4}$ miles northeast of Lake Arthur.
- Sec. 15, T. 24 S., R. 27 E., 6 miles east of Carlsbad.
- NE. $\frac{1}{4}$ sec. 18, T. 22 S., R. 27 E., $1\frac{1}{4}$ miles south of Carlsbad.
- Sec. 10, T. 20 S., R. 25 E., 15 miles northwest of Carlsbad.
- Sec. 27, T. 19 S., R. 23 E., 30 miles northwest of Carlsbad.
- Sec. 16, T. 19 S., R. 26 E., $1\frac{1}{4}$ miles north of Lakewood.
- SE. $\frac{1}{4}$ sec. 28, T. 18 S., R. 26 E., in Dayton.

The hole $1\frac{1}{2}$ miles south of Carlsbad penetrated red beds to 300 feet; anhydrite, 302 to 406 feet; rock salt, 460 to 744 feet; limestone, black in lower part, 744 to 1,748 feet; and sandstones and shales, 1,748 to 2,071 feet. The hole near Orchard Park, 10 miles south of Roswell, penetrated beds predominantly red to 534 feet, limestones and red clays to water sand at 810 feet and limestones, from 810 to 2,295 feet. A 2,966-foot boring northeast of Lake Arthur penetrated red shales with gypsum to 534 feet, below which limestone was the principal material. A large artesian flow was found at 1,205 feet.

STAKED PLAINS REGION.

In the Staked Plains region, the high plateau east of Pecos Valley, the beds lie in a general monocline with eastward dips at very low angles. Doubtless, however, there are many local irregularities in the amount and direction of dip, and there may be low domes and arches and shallow basins. The region is covered by a mantle of Tertiary sand and gravel 100 feet or more thick which conceals the underlying red beds. These rocks, however, are exposed all around the edges of the plateau and have been penetrated by borings. They are mostly red shale with thin layers of limestone and deposits of gypsum. They are underlain at moderate depths by a thick succession of older red beds and limestones containing widespread deposits of salt, anhydrite, and gypsum. To the north and possibly locally in other areas thin masses of earlier Cretaceous sandstone lie between the red beds and the overlying mantle of Tertiary deposits. The succession and structure in the red beds have not been ascertained. In 1920 wells prospecting for oil were in progress at Kenna, at a point 4 miles southeast of Garrison, and 10 miles southeast of Portales. In the last a depth of 900 feet was attained, all in red beds.

CERRILLOS BASIN.

The Cerrillos coal basin is a syncline that contains coal measures of Mesaverde age, overlain by the Galisteo sandstone, of supposed early Tertiary age. The axis of the basin extends east and southeast across the west-central part of Santa Fe County. Cerrillos is on its north slope, and the coal-mining town of Madrid is near its center. Most of the structural features have been presented by Johnson²⁷ and Lee.²⁸ To the south, north, and east the strata are cut by thick masses of early Tertiary igneous rock and penetrated by numerous dikes. To the west the basin is cut off by a fault, the country to the

²⁷ Johnson, D. W., *Geology of the Cerrillos Hills, N. Mex.*; School of Mines Quart., vol. 24, pp. 173-246, 303-350, 456-500; vol. 25, pp. 69-98, 1903.

²⁸ Lee, W. T., *Stratigraphy of the coal fields of northern New Mexico*; Geol. Soc. America Bull., vol. 23, pp. 571-686, 1912; *The Cerrillos coal field, Santa Fe County, N. Mex.*; U. S. Geol. Survey Bull. 531, pp. 285-312, 1913.

northwest is covered by a recent lava sheet, to the northeast there is a heavy covering of the Santa Fe formation, and to the south and southwest lies the laccolithic igneous mass of Ortiz Mountain. The rocks below the Mesaverde formation rise in regular succession to the northwest, the lowest formation exposed being the top of the red beds. (See Pl. XXXIX, A, p. 220.) To the east there is a similar rise to the long monoclinal slope east of Galisteo. No subordinate domes or anticlines were observed. Several deep holes have been bored in the basin in a search for coal, and no gas or oil was reported in them.

UPPER RIO GRANDE VALLEY.

The valley of the Rio Grande in Taos, Rio Arriba, and Santa Fe counties is occupied by thick deposits of the sands, loams, and gravels of the Santa Fe formation (Miocene and Pliocene), overlain in part by lavas that have flowed down the valley in relatively recent geologic time. The underlying rocks are probably very largely pre-Cambrian granites and schists similar to those which constitute the adjoining Rocky Mountains on the east and appear in the scattered outcrops in the high ridges on the east side of Rio Arriba County. These rocks do not offer any prospects whatever for oil or gas. It is probable that some portions of the bottom of the basin are underlain by limestones and sandstones of the Magdalena group, which appear so extensively in the Rocky Mountains to the east. From Santa Fe to Truchas these rocks dip under the valley, but how far they extend in that direction can not be determined without test borings. Pre-Cambrian schists appear in the bottom of the valley at Glenwoody, and along the west side of the valley granite or schist extends down to the great lava flow at Tres Piedras, Petaca, and Ojo Caliente.

SANDIA AND MANZANO MOUNTAINS AND SIERRA DE LOS PINOS.

GENERAL RELATIONS.

The Sandia Mountains, which lie on the east side of the Rio Grande east of Albuquerque, mark an uplift of considerable magnitude which is continued southward in the Manzano Mountains and the Sierra de los Pinos, extending into the central eastern portion of Socorro County. This series of ranges presents a continuous exposure of granite, schist, quartzite, and other pre-Cambrian crystalline rocks along its steep west face, as shown in Plate XXXVII, and long slopes of limestones of the Magdalena group on its east side, which extends to Estancia Valley. Along part of its west face there is considerable faulting, with the downthrow on the west side, but the relations in this direction are obscured by the heavy cover of sand and talus that slopes to the Rio Grande valley. Sections 1 to 3 in figure 26 show the principal structural relations of this series of ranges.

The monocline on the east side presents a gradual, nearly regular easterly dip for many miles, but locally there are minor flexures, anticlines, and domes, which may possibly present conditions favorable for oil or gas. One of the most notable of these is the faulted anticline north of Tijeras, some features of which are shown in figure 25. At the north end of the range, a few miles northeast of Algodones, the general anticline of the Sandia Mountains pitches gradually beneath the surface, and this may prove to be a favorable structural condition for oil or gas if these materials are present. The

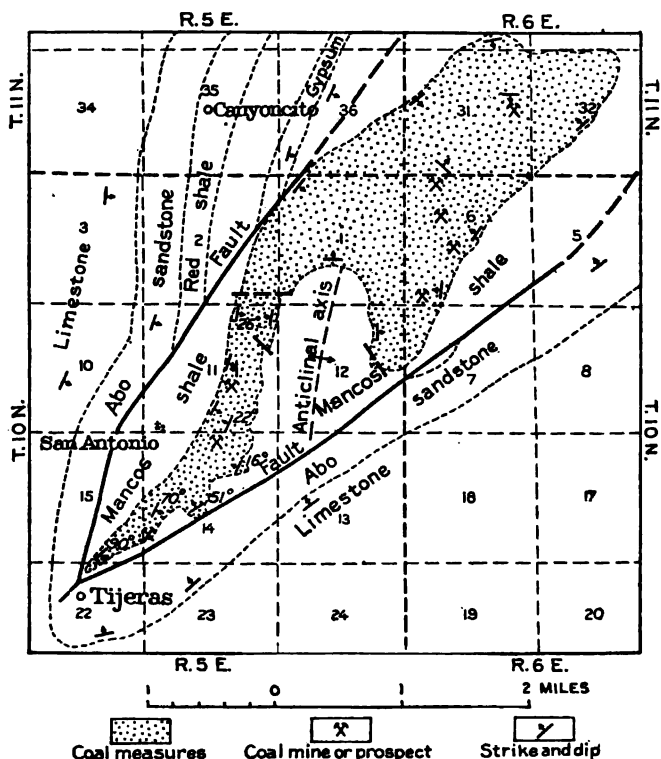
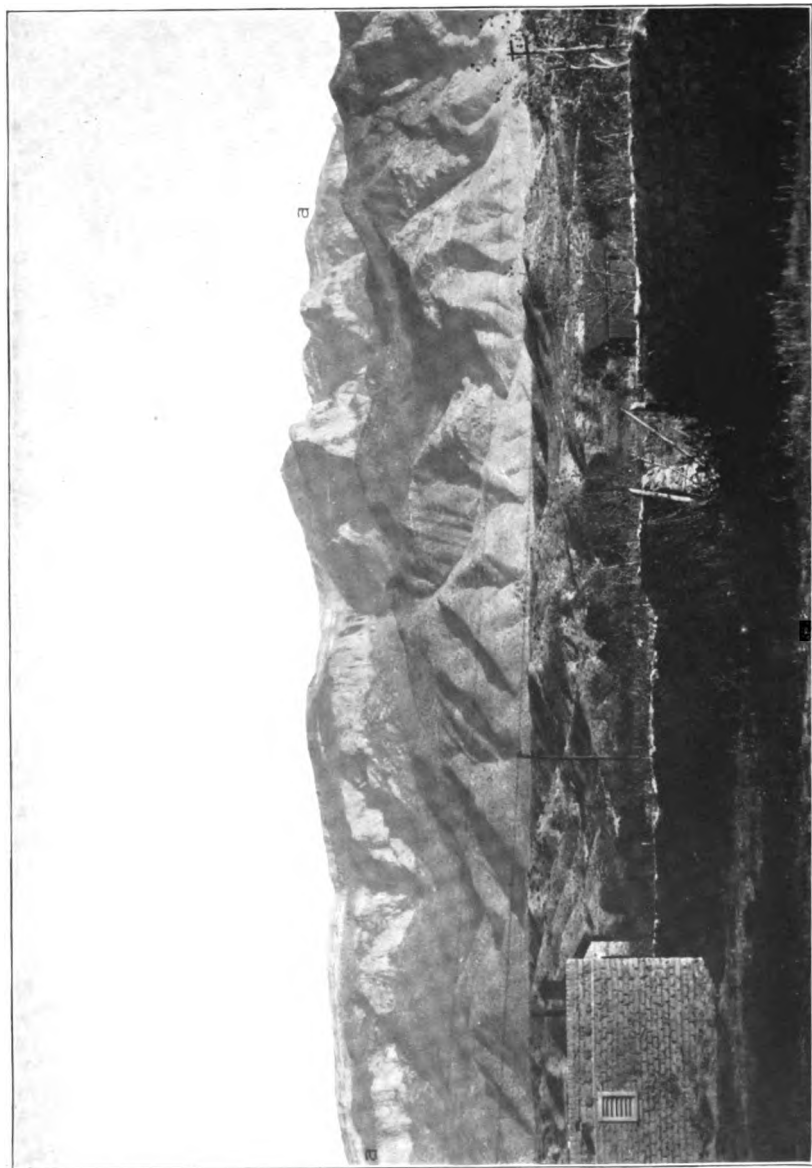


FIGURE 25.—Map showing relation of anticline in Tijeras coal field, on east slope of Sandia Mountains, east of Albuquerque, Bernalillo County, N. Mex.

Magdalena group, which lies directly on the granite and other crystalline rocks, is about 1,500 feet thick and comprises extensive deposits of sandstone in its lower portion and massive limestone in its medial and upper portions. Although there is no direct evidence that there is oil in this formation, it may be desirable to drill test holes in the domes near Chilili, as well as in the northward-pitching anticline at the north end of the uplift. In this anticline the Permian, Triassic, Jurassic, and Cretaceous rocks pass over the axis, and possibly they include some strata favorable for the occurrence of oil or gas. The anticline north of Tijeras may also merit testing, for it includes a thick mass of Cretaceous strata. (See fig. 25.)

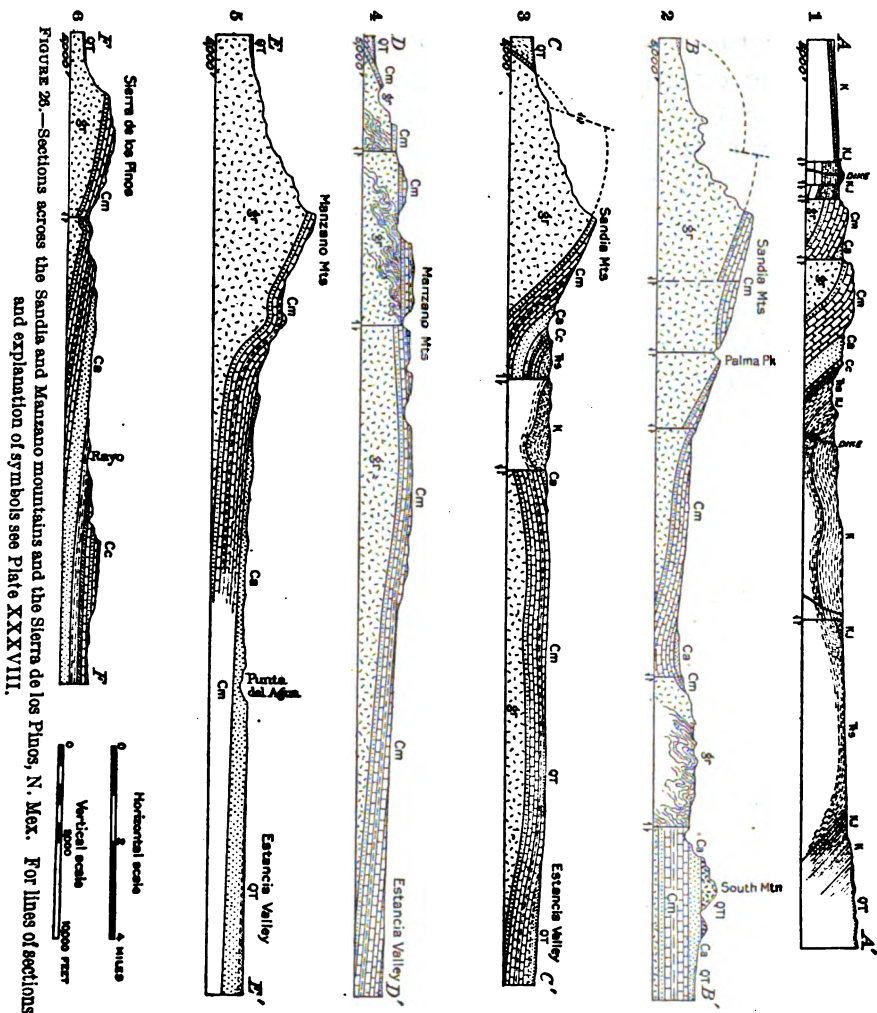


WEST FRONT OF SANDIA MOUNTAINS AT BERNALILLO, N. MEX.

a, Sandia formation on granite, etc.

DEEP BORINGS.

Test wells sunk several years ago on Tonque Creek 10 miles east of Algodones were unsuccessful, but they were situated on the eastward-dipping monocline east of the main Sandia axis. A boring in prog-



ress early in 1919 about 2 miles west of Eastview is also on the eastward-dipping monocline and will have to penetrate 900 feet or more of the Abo red sandstone before reaching the Magdalena group. The structural conditions in the vicinity of this well are shown in section 5, figure 26. A hole 1,100 feet deep bored at Abo siding by the Atchison, Topeka & Santa Fe Railway Co. obtained considerable

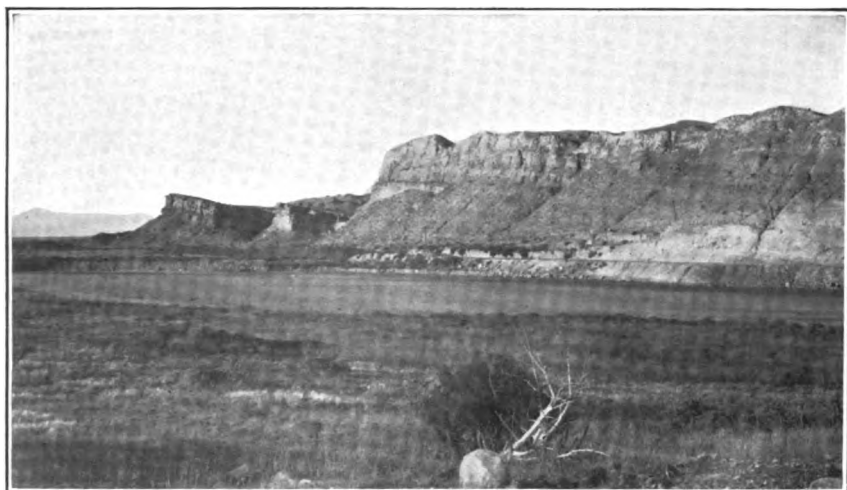
saline water.³⁰ The material penetrated was sandstone and shale, nearly all red and representing almost the full thickness of the Abo sandstone, here dipping at a low angle to the east. This hole shows practically the same conditions as those at Eastview, except that at the latter place there is a thick cover of gravel and sand.

If oil pools are developed in the Pecos Valley, it is likely that well-located test holes will be drilled in the region just described.

RIO GRANDE VALLEY IN CENTRAL NEW MEXICO.

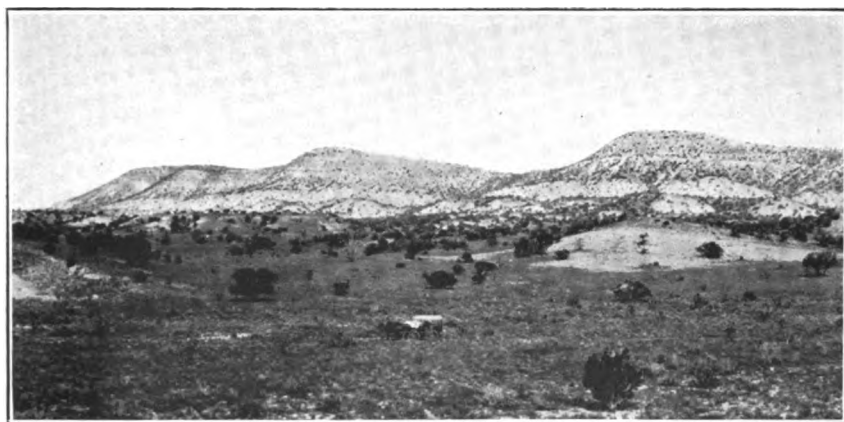
South of the Valle Grande Mountains and White Rock Canyon the valley of the Rio Grande widens greatly, and from Bernalillo County nearly to Socorro, a distance of 60 miles, it is 30 miles wide. This broad valley is floored by a thick body of loam, sand, and gravel of the Santa Fe formation, largely covered by talus from the adjoining slopes and alluvium in the valley bottom. The underground structure has not been determined, for the few borings that have been made are not sufficiently deep to reach the hard-rock strata and the relations exposed in the adjoining ridges do not indicate the structure. As shown in figure 26, the entire west front of the Sandia and Manzano mountains and the Sierra de los Pinos consists of granite, schist, and other pre-Cambrian rocks, with a few small showings of westward-dipping limestones of the Magdalena group at the foot of the range. Near La Joya and on the east slope of the Sierra Ladrones granite appears, which may indicate that this rock underlies a considerable portion of the valley. Along the west side of the valley are areas of the Magdalena group and some of the immediately overlying sandstones and limestones, but they are cut off by a fault, so that the relations to the east are not indicated. Along the valley of Rio Puerco in most of Bernalillo County the Mancos and overlying higher Montana rocks are exposed, but they also are cut off to the east by a fault. It seems probable that although the west side of the Sandia-Manzano-Pinos uplift is marked by a fault of considerable amount, the dropped westward-dipping limb of the anticline lies west of this fault, and that there is a continuous series of westward-dipping sedimentary formations extending along the east side of the valley in Valencia, Bernalillo, and Sandoval counties. The valley is therefore probably a basin underlain by a regular succession of sedimentary strata from the Magdalena group to beds high in the Cretaceous, some of which come to the surface in the Puerco Valley west of Albuquerque. It is of course possible that a syncline of this character might be interrupted by domes or anticlines or other structural features favorable for the accumulation of oil or gas. Owing, however, to the heavy covering of the young formations in the valley it is not possible to advance any definite opinion in this

³⁰ The railroad chemist reported that water from a depth of 1,045 feet contained 1,710 grains per gallon of saline materials, comprising about $\frac{1}{2}$ sodium chloride, $\frac{1}{4}$ sodium sulphate, $\frac{1}{4}$ sodium carbonate, and $\frac{1}{4}$ calcium carbonate expressed in these probable combinations.



A. DAKOTA SANDSTONE ON WEST SLOPE OF CERRILLOS BASIN, N. MEX.

Two miles east of Rosario station, Atchison, Topeka & Santa Fe Railway. Thick bed of gypsum of Todilto formation in lower slope.



B. WEST FRONT OF CHUPADERA MESA, N. MEX., LOOKING NORTH.

Limestone and gypsum of Chupadera formation.

regard. In places the sandstones of the Santa Fe formation dip in various directions, but this structure should not be expected to continue downward into the Cretaceous and underlying rocks, to which the Santa Fe formation is entirely unconformable.

The only deep borings reported in this area are two 500-foot holes for water at Becker and Bodega. The hole at Becker penetrated red clay with "gravel" intercalated to 375 feet and solid red clay below. The hole at Bodega, which is 10 miles southeast of Belen, was in sand to 290 feet, light clay from 290 to 340 feet, and red clay from 340 to 500 feet. The formations represented by these materials are not identified. They may all be either Pleistocene or late Tertiary.

CHUPADERA MESA.

GENERAL RELATIONS.

Chupadera Mesa is a high plateau covered with limestone that occupies the eastern part of Socorro County and extends northward into Mesa Jumanes, in the southern part of Torrance County. Its higher portions in the high escarpment 6 miles south of Mountainair reach an altitude considerably above 7,500 feet. In greater part the strata in the mesa have a general monoclinical structure, with a slight nearly uniform dip to the east and southeast. The mesa presents on the north and west high cliffs of sandstone and limestone, as shown in Plate XXXIX, B.

STRATIGRAPHY.

The entire surface of Chupadera Mesa has a thick capping of limestone, but some of the canyons expose underlying sandstones and lower limestone members. All these beds are part of the Chupadera formation, which in this area has a thickness of about 1,400 feet. It is underlain by the red sandstone of the Abo formation, nearly 1,000 feet thick, which in turn lies on 1,200 to 1,500 feet of limestones with included beds of shale and sandstone belonging to the Magdalena group. The lower beds of the Magdalena group, which lie on granite and schists, are largely sandstone.

LOCAL STRUCTURE.

The principal structural features and relations of Chupadera Mesa are indicated in the sections in figure 27. The higher part of the mesa consists of a monocline dipping gently to the southeast on the east slope of the Oscura anticline. Careful inspection of the area, however, may reveal some irregularities in this structure. On the west side of the mesa there is a prominent anticline which marks the northern continuation of the uplift of the Sierra Oscura. (See fig. 27.) This arch pitches down to the north and passes into the mesa in T. 1 N., where it appears to merge into the general monocline. In Tps. 1, 2, 3, and 4 S., however, this anticline presents favorable

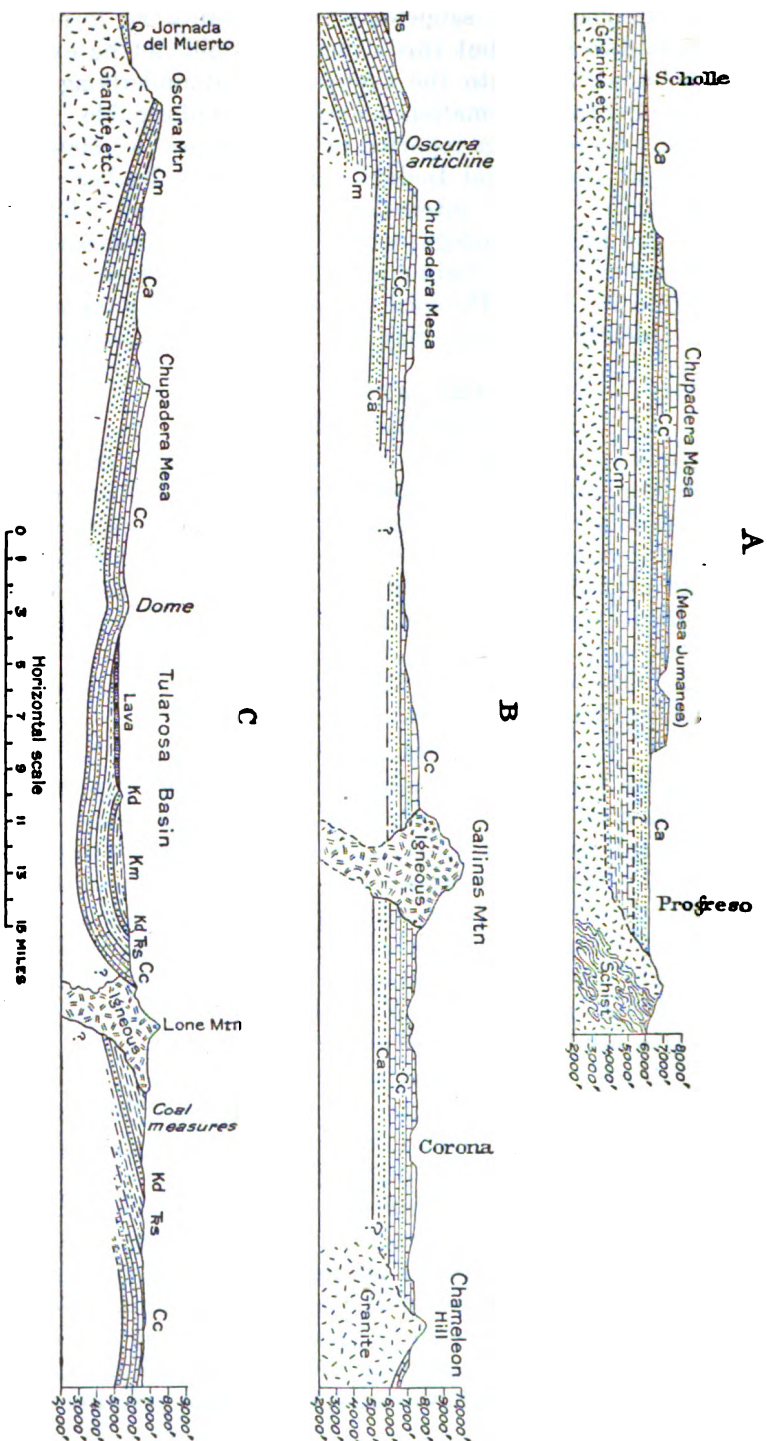


FIGURE 27.—Sections across Chupadera Mesa, in the southern part of Torrance County and the eastern part of Socorro County, N. Mex., showing relations to some adjoining ridges. A, From Scholle to Progreso; B, from a point north of the north end of Oscura Mountain to Chameleon Hill, northeast of Corona; C, from Oscura Mountain through Lone Mountain near Whiteoaks. Q, Quaternary; Km, Mancos (?) shale; Kd, Dakota (?) sandstone; Cc, Chupadera formation; a, Abo sandstone; Cm, Magdalena group.

structural conditions, and oil or gas, if they are present in this region, may possibly be found in the Magdalena group at depths of 1,000 to 2,000 feet. A small dome on the east slope of the mesa, with its crest in T. 6 S., R. 9 E., shown in section C, figure 27, may also be of importance.

TULAROSA BASIN.

GENERAL RELATIONS.

Most of the surface of Tularosa Basin from Carrizozo southward is covered by sand, lava, and wash, but data obtained at intervals along its edges indicate that the general structure is synclinal. There is some faulting along the edges and possibly also in its central part, toward the south. The idea sometimes advanced that it is simply a down-faulted block is erroneous. In Plate XL and figure 28 are shown the principal structural features. Near Carrizozo there is a thick eastward-dipping succession from Chupadera limestones on the west to Cretaceous rocks as high as coal measures of Mesaverde age on the east. Near Alamogordo a great thickness of eastward-dipping limestones and sandstones constitute the high Sacramento Mountains. On the west side of the basin is the east face of the San Andres Mountains, with westward-dipping Paleozoic limestones surmounting steep slopes of granites and schists, and to the northwest are the eastward-dipping cuesta of the Sierra Oscura and Chupadera Mesa. An anticlinal arch crosses the basin diagonally southwest of Carrizozo and west of Oscuro, passes under the eastern part of Alamogordo, rises in the west face of the Sacramento Mountains, and continues southward into the Hueco Mountains. The structure west of this anticline to the foot of the San Andres Mountains is concealed by the valley fill.

STRATIGRAPHY.

The rocks in the Tularosa Basin region comprise strata ranging from Cambrian to late Cretaceous in age, on a basement of pre-Cambrian granite and schists. A considerable thickness of gravel and sand occupies the center of the basin, and volcanic rocks are abundant, including an older porphyry and a thick succession of late Tertiary fragmental and effusive sheets, dikes, and stocks of various kinds. A long, narrow recent lava flow, "the Malpais," is conspicuous in the center of the basin. The following table shows the principal features of the strata, mainly as exhibited in the adjoining Sacramento and San Andres mountains. The rocks from Cambrian to Carboniferous age have been described in considerable detail in a previous report.²¹

²¹ Darton, N. H., A comparison of Paleozoic sections in southern New Mexico: U. S. Geol. Survey Prof. Paper 108, pp. 31-55, 1917.

Sedimentary formations in Tularosa Basin and adjoining ridges.

Age.	Group and formation.	Character.	Thickness (feet).
Upper Cretaceous.	Mesaverde (?) formation.	Sandstone and shale, coal bearing.	630
	Mancos (?) shale.	Shale; some sandstone; limestone in lower part.	900
	Dakota (?) sandstone.	Sandstone, massive, hard, gray to buff.	150
Triassic.		Red sandy shales with layers of brown sandstone and limy concretions.	340
Permian.	Manzano group. Chupadera formation.	Upper part limestones and gray sandstones; lower part gypsum, soft red sandstones, then limestones and gypsum.	1200-1600
	Abo sandstone.	Brown-red sandstones and red sandy shales; thin toward the south.	500-900
Pennsylvanian.	Magdalena group.	Limestones with beds of shale and sandstone; several sandstone beds in lower part.	2200-2500
Mississippian.	Lake Valley limestone.	Coarsely crystalline limestone and limy shale.	0-150
Devonian.	Percha shale.	Gray shale.	0-125.
Silurian.	Fusselman limestone.	Limestone, massive, dark above; weathers white below.	0-200
Ordovician.	Montoya limestone.	Massive limestone, cherty above, dark below, sandy at base.	0-200
	El Paso limestone.	Limestone; weathers light gray, slabby in part.	0-350
Cambrian.	Bliss sandstone.	Sandstone, massive, gray.	0-125
Pre-Cambrian.		Granites, schists, and quartzites.	

The Bliss sandstone is coarse and porous. The overlying limestones present considerable variety in character. Some of them are compact, some are mixed with considerable clay and sand, and some are cherty. The Fusselman limestone, which is especially massive and compact, thins out not far north of latitude 36°. The base of the Montoya is a sandstone at most places, and locally this member is 10 to 20 feet thick. The Percha shales are dark and carbonaceous and should be tested. The basal portion of the Magdalena group includes much coarse gray sandstone, and layers of sandstone occur at intervals higher up in the formation. These sandstones would afford suitable reservoirs for oil. It is not known, however, whether

massive, compact gray limestone, thick gypsum beds, red sandstone, and porous gray sandstone. The gray sandstones may prove to be oil bearing in some portions of the area. They are known to underlie the upper part of the basin and are believed to extend far southward under it, as shown in the cross sections in figure 28.

LOCAL STRUCTURE.

The anticline of the Sacramento Mountain front is first manifested in an anticline or dome west of "the Malpais" (recent lava flow), 15 miles northwest of Carrizozo. Its axis crosses the basin west of Oscuro, where it is marked by a dome of limestone of the Chupadera formation in T. 8 E., R. 9 S., and appears in the Phillips Hills, which present a complete arch of the Chupadera formation along their western slope. Limestone at the top of the Magdalena group rises on this axis a short distance southeast of Tularosa, and the uplift is well exposed from La Luz to High Rolls, where there are two arches and an intervening basin containing the Abo sandstone. (See fig. 24, p. 209.) The anticline is well defined east of Alamogordo and in Alamo Canyon. South of the latter place the beds on the axis rise rapidly, and near the center of T. 19 S., R. 11 E., the basement of granite is brought up at the foot of the west front of the mountain. Doubtless in this region for some distance the west limb of the uplift is faulted, with the dropped block on the west side. A diagonal fault passing into the Sacramento Mountain front is well exposed 5 miles south-southeast of Alamogordo. South of Escondida the anticline pitches down again to the south, and its wide, low arch is well exhibited southeast of Turquoise, as shown in section 6, figure 28.

Limestone of the Chupadera formation (the same as that on top of the mountain at Cloudcroft) is exposed in scattered outcrops along the desert, forming Cerrito Tularosa, Tres Hermanos, and some of the ridges of the Jarilla Range west of Turquoise. In the Jarilla Range and in the eastern part (One Butte) of Tres Hermanos this formation is cut by igneous rocks. In these outlying exposures the beds lie nearly horizontal or dip to the west at a very low angle.

West of these small outcrops there are no rock exposures until the east slope of the San Andres Mountains is reached, a distance of 22 to 25 miles. This range is an anticline, and outcrops along the east foot of the northern part of the range indicate the eastward-dipping monocline on its east slope. In the higher eastern ridges of this range, especially at its north and south ends, the anticline is considerably faulted, both longitudinally and transversely. (See section 3, fig. 28.) In T. 20 S., R. 5 E., there are several small exposures of eastward-dipping rocks at the foot of the mountains, and where the east front of the range bears toward the east again

for a few miles in Tps. 9, 10, and 11 S., similar features are exposed, indicating very clearly that the east front of the mountain is part of an anticline. This being the case, the east limb of the uplift doubtless forms the west limb of a syncline, in which Chupadera limestone is exposed in the Jarilla Hills, Tres Hermanos, Cerrito Tularosa, and Phillips Hills. It is quite likely that this syncline holds Triassic "Red Beds" and a thick body of Cretaceous shales and even the coal measures and overlying early Tertiary deposits. Originally the wide Tularosa Basin was much deeper, its bottom being excavated in the softer rocks, which have later been covered by sand and gravel from the adjoining mountains. Minor structural features in or adjoining the Tularosa Basin are found in the region north of Oscuro and Carrizozo. The beds of Chupadera limestone are arched in an elongated dome in the Phillips Hills and in an oval dome in the western part of Tps. 6 and 7, R. 9 E. Both these domes are on the anticline above referred to. A small dome of similar character exists in the northeastern part of T. 9 S., R. 8 E., and another has its apex in the center of T. 5 S., R. 12 E., about 5 miles southwest of Ancho. In these uplifts the gray sandstones of the Chupadera formation are at no great depth and may yield oil, but in the 800 to 1,000 feet of red sandstones of the Abo formation next below the prospects are less promising. In the still lower Magdalena group there are several beds of sandstone, especially near its base. The thickness of this group is somewhat more than 2,000 feet. In the northern part of the area it lies on the pre-Cambrian granite and schist, but to the south Mississippian to Ordovician limestones intervene. These limestones are 600 feet thick in the west face of the Sacramento Mountains southeast of Alamogordo.

DEEP BORINGS.

Several deep borings have been made in the Tularosa Basin. During 1918 a hole was being bored for oil 10 or 15 miles southwest of Alamogordo, but nothing has been learned as to its record. Two holes half a mile north of Dog Canyon station, in the NE. $\frac{1}{4}$ sec. 14, T. 18 S., R. 9 E., were 1,235 and 1,800 feet deep. The record furnished by the El Paso & Southwestern Railroad Co. showed "red clayey material" with deposits of sand and gravel 20 to 25 feet thick every 300 or 400 feet. From the record it is impossible to recognize the formations penetrated; the material may be all valley fill, but it is not unlikely that the lower part of the Chupadera formation and possibly also the Abo sandstone were penetrated. A 1,004-foot hole bored by the railroad company about $1\frac{1}{2}$ miles west of Alamogordo, in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 26, T. 16 S., R. 9 E., was reported to have penetrated 10 feet of limestone at a depth of 130 feet, lying on 85 feet of yellow clay and clay stone, 250 feet of red clay, alter-

nating yellow, red, blue, and yellow clay at 450 to 500 feet, and "clayey material" from 500 feet to the bottom. This record doubtless represents the same conditions as in the Dog Canyon hole. A 960-foot hole at Orogrande passes through "granite" (porphyry) and similar igneous rocks to a depth of 590 feet, where the Carboniferous limestone (probably Chupadera) was entered. Near the south margin of sec. 3, T. 22 S., R. 8 E., a shaft 250 feet deep with a 160-foot drill hole in its bottom revealed 235 feet of limestone underlain by "granite" (porphyry). An 800-foot hole bored by the railroad

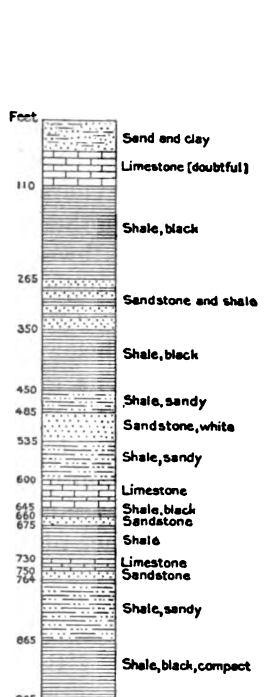


FIGURE 29.—Log of deep boring at Oscura, N. Mex.

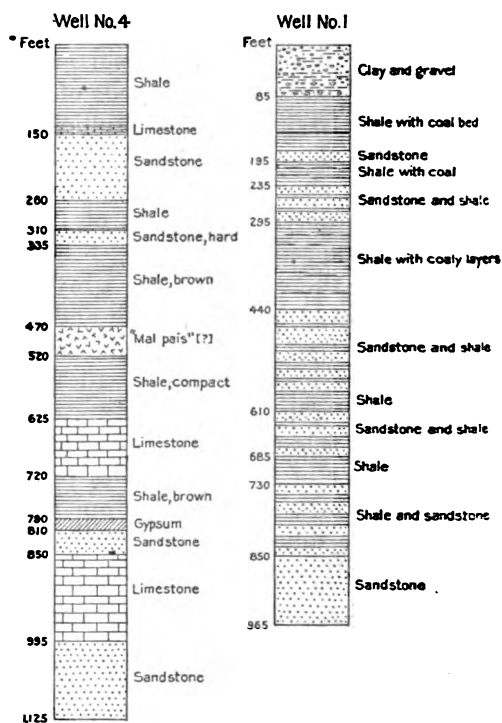


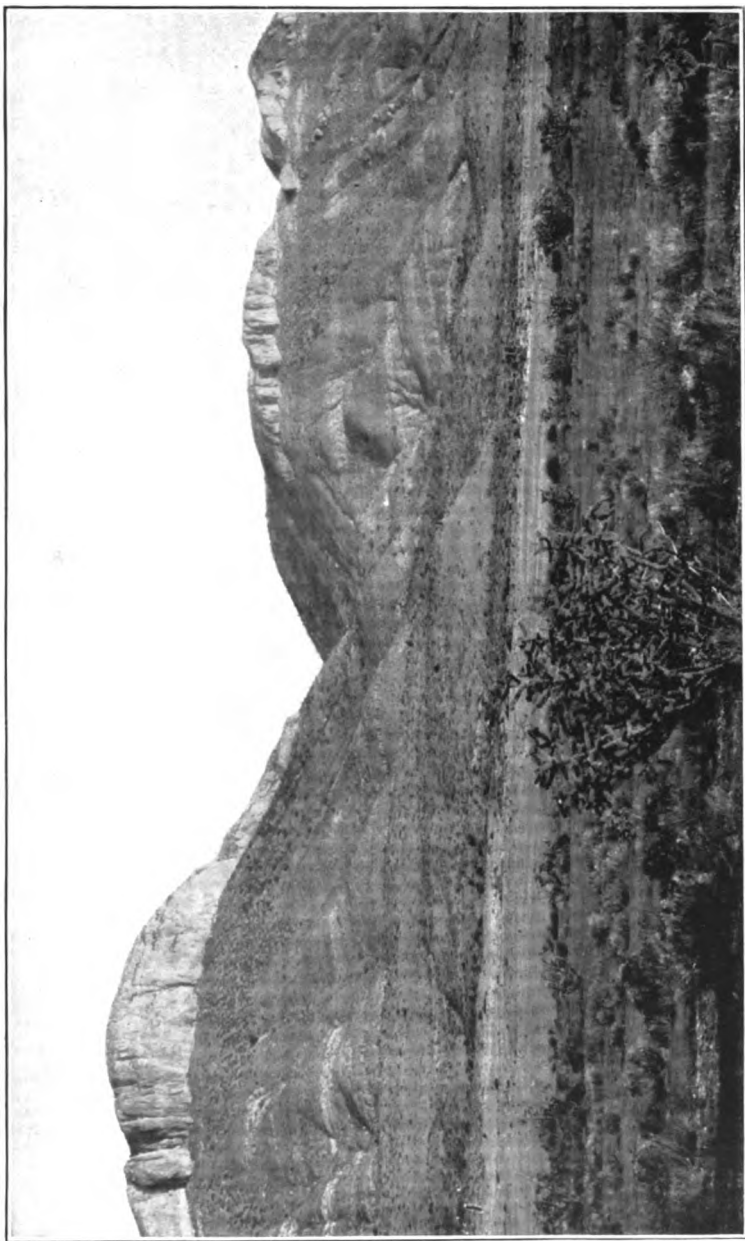
FIGURE 30.—Logs of two railroad wells at Carrizozo, N. Mex.

company at Temporal is reported to have penetrated 185 feet of wash, 20 feet of pink clay, and 595 feet of alternating gravel, sand, clay, and conglomerate.

A hole drilled for oil in sec. 34, T. 13 S., R. 7 E., about 12 miles northwest of Tularosa, is said to have reached a depth of 1,600 feet.

Two wells sunk by the railroad company at Oscura are 965 and 489 feet deep. The log of the deeper one is given in figure 29. The strata are apparently all Cretaceous and lie below the coal measures that crop out a short distance northeast of Oscura.

The El Paso & Southwestern Railroad Co. sunk several wells at Carrizozo, and one of them reached a depth of 1,125 feet and obtained



PILOT KNOB, ON WEST SLOPE OF SAN ANDRES MOUNTAINS, N. MEX., LOOKING WEST.

Massive limestone of Chupadera formation.

excellent water. The logs of the two deeper ones are given in figure 30. The strata penetrated appear to be Cretaceous and possibly include also the underlying Triassic red shale and Chupadera formation.

An 850-foot well bored by the railroad company 2 miles east of Ancho penetrated alternating red and blue clay to 340 feet, red shale from 340 to 415 feet, sandstone from 415 to 425 feet, red clay from 435 to 715 feet, including a 50-foot bed of gypsum, red sandstone from 715 to 795 feet, and red clay and shale from 795 to 855 feet, presumably all beds above the Chupadera formation or possibly including the upper member of that formation.

SAN ANDRES MOUNTAINS.

The San Andres Mountains form a long, narrow ridge that extends through the northern part of Dona Ana County and the southeastern part of Socorro County and separates the Tularosa Basin on the east from the Jornada del Muerto on the west. As shown in cross sections 3, 4, 5, and 6, figure 28, and sections 3, 4, and 5, figure 31, the ridge consists mainly of a monocline of limestones and red beds dipping to the west and passing under the Jornada del Muerto. The uplift in general, however, is an anticline, and eastward-dipping strata are exposed at its foot toward the north and south ends of the ridge. For many miles along the steep eastern face of the mountains there are exposures of pre-Cambrian granites and schists capped by the westward-dipping Ordovician to Pennsylvanian limestones. The Pennsylvanian limestone constitutes most of the summit and higher western slopes of the range and finally passes beneath the red sandstones of the Abo, and these in turn under the sandstones and limestones of the Chupadera formation (see Pl. XLI), which slope down to the desert at the western foot of the range. As the structural conditions in a mountain range of this sort are entirely unfavorable for oil or gas, no further consideration will here be given to the details.

JORNADA DEL MUERTO.

GENERAL RELATIONS.

The name Jornada del Muerto (Spanish, journey of the dead) is applied to the long, wide desert valley extending through the eastern part of Socorro County and southward across the eastern part of Sierra County into Dona Ana County, a distance of 125 miles. To the east rise the high San Andres Mountains and Sierra Oscura and Chupadera Mesa, and along the western margin of the valley flows the Rio Grande. Its remarkably smooth and nearly level floor consists mostly of sand or loam which in an area southeast of San Marcial is covered by a large sheet of recent lava. In most places

the deposit of sand, loam, and gravel is so thick that the rocks are not exposed, but the general structure is plainly indicated by the relations of the formations in the adjoining ridges, and some additional data are afforded by records of a few widely scattered

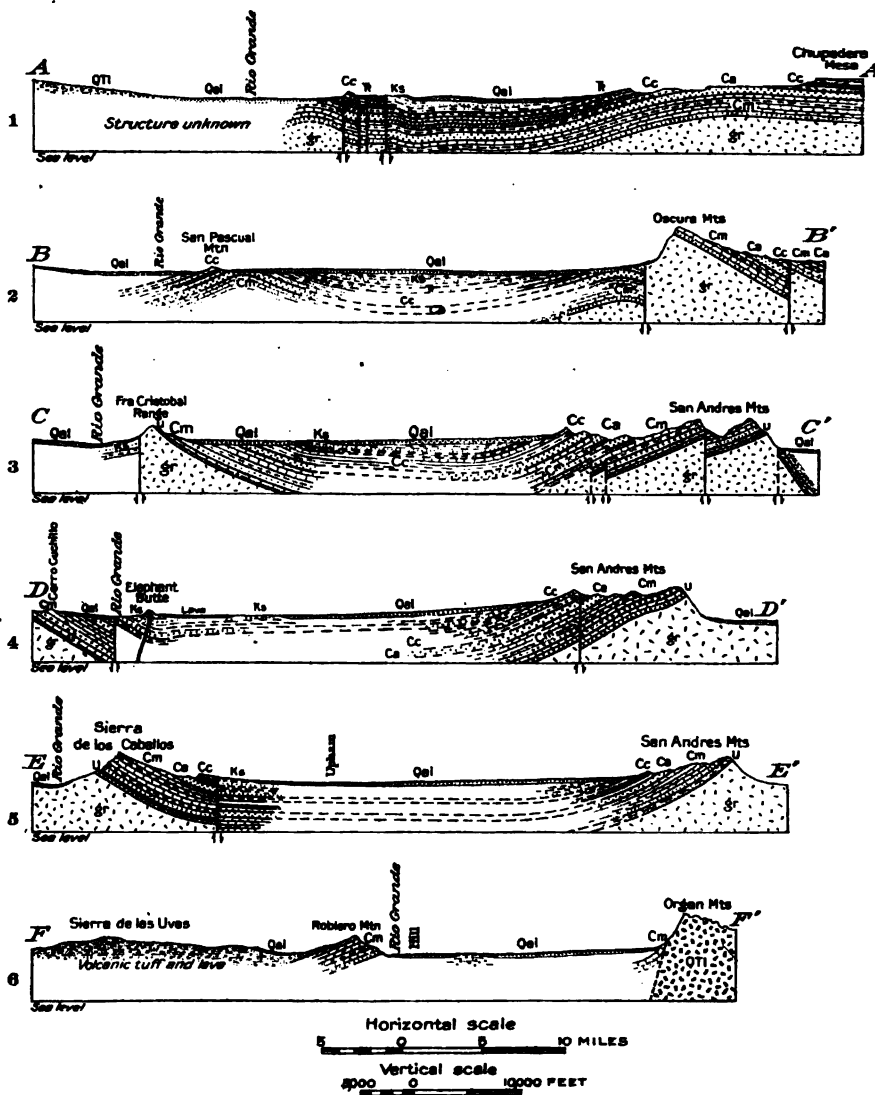


FIGURE 31.—Sections across the Jornada and del Muerto, N. Mex. For lines of sections and explanation of symbols see Plate XLII.

wells. The principal data and their interpretation are shown in Plate XLII and figure 31. The chief feature is a long, moderately narrow syncline, which is not very deep, for the dips appear to be gentle at most places.

LOCAL STRUCTURE.

Local anticlines or domes may occur in this valley, but except for those on the margin no evidence can be obtained as to their existence until numerous borings are made. It appears unlikely that many such features are present. The anticline at Carthage and Prairie Springs and the prominent plunging anticline at the north end of the Oscura uplift, in Tps. 2, 3, 4, and 5 S., R. 6 E., are outside of the main basin. In the valley of Arroyo Chupadera, at the north end of the Jornada syncline, the shallow basin of limestone of the Chupadera formation contains a thin remnant of Triassic red shales, mostly hidden by loose sand. The basin deepens gradually toward the south, and in T. 4 S. Cretaceous shales and sandstones appear in regular order. These rocks are extensively exposed about Carthage, where the higher sandstones carry a coal bed that is extensively mined. The structural relations from Prairie Spring to Carthage are described on page 238. Early Tertiary conglomerate crops out south and east of Carthage, and this formation may extend widely under the basin to the south. The Cerro Colorado in this vicinity is a mass or group of masses of igneous rocks of the Tertiary volcanic series. Probably these rocks are not of wide extent underground. The eastward-dipping limestone of the Magdalena group in the ridge in T. 6 S., Rs. 4 and 5 E., appears to be cut off by a fault on its west side, for Cretaceous sandstone crops out a short distance southwest of its foot, and wells 250 and 300 feet deep in this vicinity are in sandstone that is reported to be coal bearing and to show traces of oil. The higher part of the west face of the Sierra Oscura, in which granite and other old crystalline rocks rise 1,500 feet or more above the Jornada, is doubtless due to a fault, but it is probable that westward-dipping rocks occur not far west of the foot of these mountains. This structure is indicated by outcrops of Cretaceous sandstone (Mesaverde?) in the southeast corner of T. 8 S., R. 4 E., and by outcrops of westward-dipping Dakota (?) sandstone in the northern part of T. 11 S., R. 3 E., and the southeastern part of T. 11 S., R. 2 E. In a well in sec. 36, T. 10 S., R. 2 E., an 18-inch bed of coal was reported at a depth of 320 feet, indicating the presence of the higher sandstones of the Cretaceous (Mesaverde?), and a similar occurrence is reported in wells in the center of T. 11 S., R. 2 E., where the sandstone lies under 60 to 70 feet of wash. A well in the east-central part of T. 10 S., R. 1 E., penetrated sandstone reported to carry coal streaks and "oil indications." In Tps. 9 and 10 S. limestone of the Chupadera formation dips gently to the west on the west slope of the San Andres Mountains and rises again on an east dip on the east slopes of the Fra Cristobal and Caballos mountains, thus forming a synclinal basin, as shown in sections 3 and 5, figure 31. A fault along the west side of the basin is traceable along the east side of the

Caballos Mountains. The basin flattens and spreads to the west near Engle and Elephant Butte, as shown in section 4, figure 31.

Wells in the Engle and Carthage regions penetrated sandstone, presumably in the Cretaceous coal measures (Mesaverde?). The 300-foot well 3 miles northeast of Engle is reported to have passed through about 100 feet of wash into hard dark-gray sandstone with a 3-foot bed of coal at 300 feet. In the Hickox well, sunk 6 miles southwest of Engle early in 1915, the Cretaceous sandstone began near the surface and a thin bed of coal with "oil indications" was reported at about 120 feet. A 1,200-foot boring was made by the Atchison, Topeka & Santa Fe Railway Co. a short distance northwest of Engle, and a 600-foot hole was sunk by the Victorio Cattle Co. 4 miles east of Engle, but no records have been obtained. A well in sec. 15, T. 14 S., R. 3 W., 5 miles west of the Hickox well, penetrated 250 feet of sandstone and found a 4-foot bed of coal. The 365-foot well at Engle is all in hard dark-gray sandstone except a few feet of wash. Similar sandstones have been penetrated in several wells in the Jornada south of Cutter, and there is every reason to believe that Cretaceous sandstone and shales occupy the basin as far south as Las Cruces. In the Point of Rocks area, San Diego Mountain, and the Dona Ana Hills the Tertiary agglomerate and lavas overlie these Cretaceous rocks, which are doubtless interrupted by dikes and other intrusive bodies of the igneous rocks.

LOWER RIO GRANDE VALLEY.

The Jornada del Muerto extends to the lower Rio Grande valley between Rincon and Las Cruces. From Las Cruces southward the valley of the Rio Grande consists of a long down slope from the mountains on the east, a trench occupied by the river, and a higher plain or mesa which extends far to the west across Dona Ana and Luna counties. This plain, the valley trench, and the slope on the east are all underlain by a thick deposit of sand and gravel which completely hides the underlying rocks over wide areas, so that their character and structure can not be determined. Ridges and knobs consisting of igneous rocks or limestone rise above the plain in places, and portions of the plain south of Afton and Aden are covered by lava flows.

A few deep holes that have been bored along the Southern Pacific and El Paso & Southwestern railroads in southern Dona Ana County throw light on the character of the underlying rocks. One at Strauss is 1,330 feet deep. Down to 120 feet the material is sand and clay on a bed of "cemented sand"; from 120 to 360 feet are yellow clay, sand, and red clay of unknown age; the material below is not reported. Three holes at Noria are 565, 600, and 1,000 feet deep. The deepest one went through 160 feet of sand, clay, and gravel; the material from

160 to 220 feet was not reported; from 220 to 1,000 feet were sand, shale, and shells alternating. The 565-foot hole was reported to have penetrated 375 feet of sand, clay, and gravel, 100 feet of shale with red clay at the top and bottom, and 90 feet of alternating shale, "pack sand," and red clay.

A hole 515 feet deep at Mount Riley siding was reported to have penetrated clay to 80 feet, alternating clay and sand from 80 to 240 feet, silt from 240 to 275 feet, and clay, gravel, and rock from 275 to 515 feet. Another one 715 feet deep was reported as follows: 0-170 feet, clay and sand with streaks of white rock; 170-280 feet, clay; 280-300 feet, clay and sand; 300-325 feet, water sand; 325-715 feet, clay, sand, gravel, and boulders, in part cemented.

A 950-foot well sunk by the Southern Pacific Co. at Lenark had the following record:

Record of deep well at Lenark, N. Mex.

	Feet.
Red soil.....	0-13
Chalky clay.....	13-15
Sandrock, hard.....	15-78
Cemented stones.....	78-125
Red clay.....	125-186
White sand.....	186-204
Sandy clay.....	204-214
Sand.....	214-226
Red clay.....	226-252
Sand.....	252-290
Cemented sand, hard.....	290-294
Red clay, hard.....	294-336
Yellow clay.....	336-382
Sand.....	382-396
Red clay, hard.....	396-428
Quicksand.....	428-446
Cemented sand.....	446-452
Clay.....	452-456
Sand.....	456-562
Red clay.....	562-590
Yellow clay.....	590-640
Sandstone, soft.....	640-666
Sandstone, hard.....	666-668
Yellow clay.....	668-700
Sand.....	700-710
Sandy clay.....	710-730
Clay.....	730-750
Sand.....	750-775
Clay, hard.....	775-781
Yellow clay.....	781-800
Sand.....	800-810
Sandy clay.....	810-840
Sand.....	840-870
Sandy clay.....	870-892
Clay.....	892-900
Sandy clay.....	900-950

A 1,077-foot hole at *Kenzin siding*, Dona Ana County, had the following record:

Record of deep well at Kenzin, Dona Ana County, N. Mex.

	Feet.
Soil and sand.....	0-50
Clay and sand.....	50-140
Cement, clay, and sand alternating.....	140-324
Solid rock.....	324-326
Sand, cement, and clay, with gravel.....	326-395
Clay.....	395-515
Clay and rocks; water.....	515-550
Solid rock.....	550-802
Conglomerate.....	802-807
Solid rock.....	807-827
Solid rock, lava (?), and conglomerate.....	827-844
Solid rock and conglomerate alternating.....	844-1,027

A 445-foot well at *Malpais siding* passed through 108 feet of clay, 262 feet of lava, and 75 feet of sand and clay.

It is difficult to interpret the records of these borings. They indicate that a diversity of rocks underlie the wide plains of southern Dona Ana County. To the south the sandstones and limestones of Comanche age may be extensively distributed, for they appear at El Paso and near Montoya and apparently were penetrated by the holes at *Noria*, *Strauss*, and *Lenark*.

EASTERN SOCORRO COUNTY.

GENERAL RELATIONS.

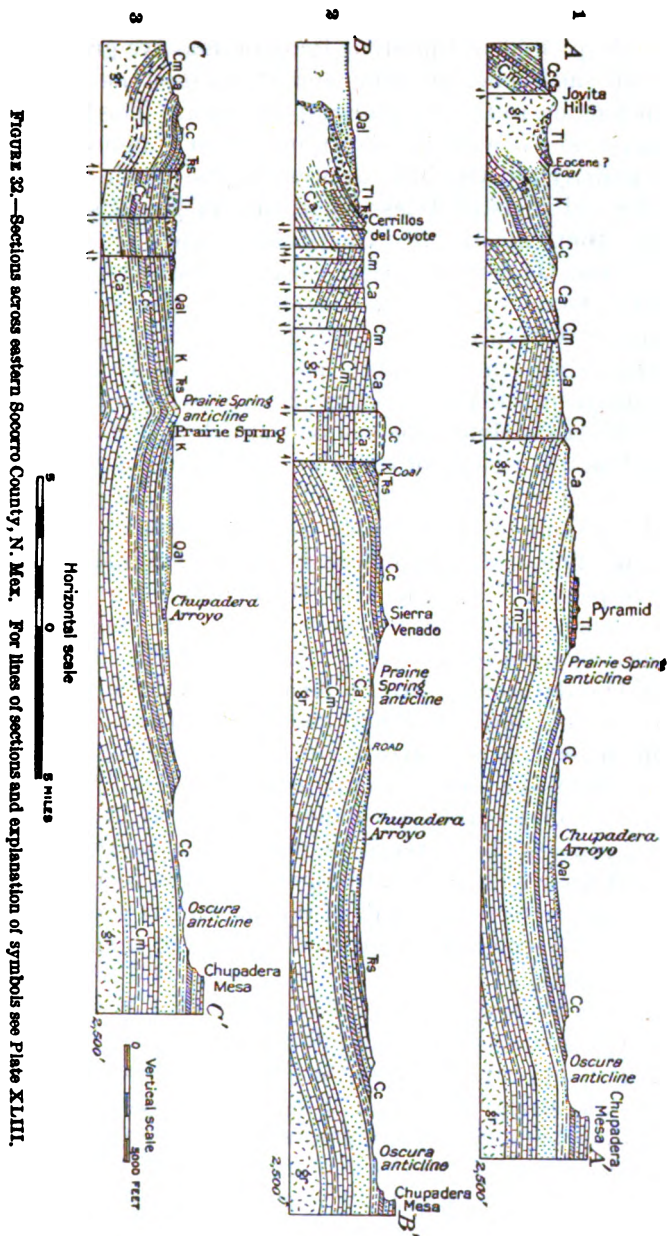
The ridges lying between Socorro and the north end of the *Jornada del Muerto* consist of limestones, sandstones, and red shales presenting somewhat complex structural relations. The dominant features are the southward prolongation of the anticline of the *Sierra de los Pinos*, complicated by faults and minor flexures, the northern extension of the *Jornada del Muerto*, and the eastern face of *Chupadera Mesa*. Plate XLIII and the cross sections of figure 32 show the principal structural features. It will be seen from these sections that nearly all the anticlines to the west are cut off by faults, which might have an unfavorable effect on the migration of oil if that substance is present. On the other hand, these faults might afford the oil an outlet from one horizon to another.

LOCAL STRUCTURE.

Cerrillos del Coyote to Carthage.—The series of high limestone ridges that begin about 5 miles east of Socorro occupy a narrow belt about 18 miles long extending from *Cerrillos del Coyote* nearly to *Carthage*. They are in greater part in Rs. 1 and 2 E. The structure is in the main anticlinal, being a continuation of the uplift of the *Sandia* and *Manzano* mountains and the *Sierra de los Pinos*. There



are many faults and minor flexures, most of them longitudinal to the main line of uplift—that is, with trend nearly north. Some of the faults, however, are transverse to this course, and the flexures have



much pitch. Some general features are shown in the sections in figure 32. The formations presented are the Magdalena, Abo, Chupadera, Triassic, and Upper Cretaceous, with more or less overlap of Tertiary

and Quaternary deposits and Tertiary igneous rocks. The underlying pre-Cambrian granite is exposed in the axis of two small uplifts about 6 miles east of Socorro.

The Cerrillos del Coyote consist of a small group of buttes (see Pl. XXXI, *B*, p. 188) of limestone lying on massive gray sandstone, with soft red sandstone, gypsum, and thin limestone on the lower slope, all belonging to the Chupadera formation. The beds dip west and are traversed by faults, as shown in section 2, figure 32. To the south the underlying Abo beds appear; to the north the limestone passes under red shale of Triassic age, and in places some Tertiary agglomerate abuts against it. On the east side the fold brings up limestone of the Magdalena group, which constitutes an extensive series of ridges to the south, where its outcrop continues to the Arroyo de las Canas, in the southeastern part of T. 3 S., R. 1 E. The Magdalena outcrop is wide in the southeastern part of T. 2 S., R. 1 E., where, as shown in section 2, figure 32, it presents an anticline (see Pl. XLIV, *B*), a syncline, and a broad anticline. On the east side of the anticline lies a basin of the Abo sandstone along the west side of R. 2 E., east of which is limestone of the Magdalena group, brought up again by a fault of considerable throw. South of Arroyo de los Pinos the anticline in the Magdalena beds rises gradually, and in the northeastern part of T. 3 S., R. 1 E., the underlying granite appears. Another parallel exposure of granite occurs in another anticline lying a short distance to the west. The axis of this anticline passes just east of Ojo del Amado (see Pl. XLIV, *B*), and the uplifted rocks are mostly buried under Tertiary and later deposits. The granite appears in several other arroyos in this vicinity. The relations along the eastern axis are well exposed near the old fire-clay pits 6 miles east of Socorro. Here, as shown in Plate XLIV, *A*, there is a fault which repeats the outcrop of the granite and the overlying quartzite and fire clay. Eastward up the arroyo a regular monocline exposes a complete section of beds of the Magdalena group and above them all the overlying Abo beds and the lower members of the Chupadera formation.

The ridges in the eastern part of T. 3 S., R. 1 E., consist of an eastward-dipping succession of limestone on gray massive sandstone, representing the upper members of the Chupadera formation, repeated somewhat by faulting, as shown in section 3, figure 32. East of these ridges the upper limestone passes beneath red shale (Triassic) and there is a fault which in the vicinity of the Armijo ranch, in the center of T. 3 S., R. 2 E., lifts the lower part of the Abo sandstone to the level of the upper limestone of the Chupadera formation. To the east are lower beds of the Chupadera formation—soft red sandstone, limestones, and gypsum beds. In sec. 25, T. 3 S., R. 2 E., these beds

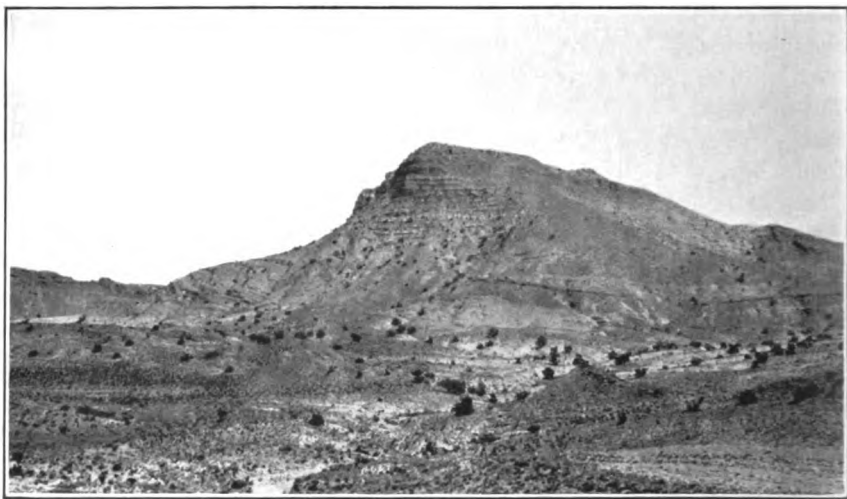


**A. BASE OF MAGDALENA GROUP 8 MILES SOUTHEAST OF SOCORRO, N. MEX.,
LOOKING NORTH.**

Beds lie on granite in foreground. Fire-clay mine and fault to right.



**B. UPTURNED MAGDALENA BEDS AT OJO DE AMADO, 7 MILES EAST-NORTHEAST
OF SOCORRO, N. MEX.**



A. MESA DEL YESO, 15 MILES NORTHEAST OF SOCORRO, N. MEX., LOOKING NORTH.
Limestone and gypsum of Chupadera formation.



B. SIERRITA MESA, NACIMIENTO UPLIFT, N. MEX., LOOKING NORTHEAST.
Todiito limestone and gypsum to left.

are upturned sharply and cut off by a fault along which appear the Abo sandstone, standing nearly vertical, and in due order to the west the Magdalena beds. West of the Magdalena is a small showing of overlapping Tertiary agglomerate.

In secs. 31 and 32, T. 3 S., R. 3 E., two anticlines bring up the Abo sandstone in the midst of an outcrop of lower beds of the Chupadera formation, and some of the higher sandstones and limestones of the Chupadera are dropped by a fault in the western part of sec. 31. At the south end of this area there is a continuous zone of high ridges of the upper limestone and sandstone of the Chupadera formation extending nearly to Carthage and having the structure shown in section 3, figure 32. There is considerable faulting but in general a regular succession from the Magdalena on the west to Triassic red shale and the Dakota (?) sandstone on the east. A strong cross fault in the center of T. 4 S., R. 2 E., gives some complexity to the structure. South of this fault there is a general downward pitch to the south, the Triassic outcrop widens, and finally the Cretaceous rocks extend across the anticline in the coal basin of Carthage. Overlying the Cretaceous beds is a conglomerate of early Tertiary age, which also appears at intervals to the north, in Tps. 2 and 3 S., R. 3 E. On the east side of this part of the Tertiary area, in the western part of sec. 1, T. 5 S., R. 2 E., there is a well-defined anticline or elongated dome of Cretaceous coal measures. On its west side is the main fault, which extends far north from the eastern part of Carthage.

Cibola Cone syncline and fault.—The southern prolongation of the anticline of the Sierra de los Pinos, pitching downward, bears on its eastern slope in T. 1 S., R. 3 E., and farther south a thick wedge-shaped mass of the Chupadera formation. On its east side the wedge is cut off by a fault with upthrow on the east that brings into view the top limestone of the Magdalena group. The resulting topographic features are strongly marked, as the hard limestone and sandstone of the Chupadera formation give rise to a prominent ridge culminating in the very conspicuous butte long known as Cibola Cone, and east of the fault the uplifted Abo sandstone presents to the west a high red escarpment. Some of these features are shown in section 1, figure 32. The Chupadera and Abo formations in the area do not present any unusual features.

Valle del Ojo de la Parida.—Structurally the Valle del Ojo de la Parida is a syncline with a regular succession of Cretaceous to Pennsylvanian rocks rising in its east side and an overlap of Tertiary igneous rocks on its west side. Possibly the igneous rocks are cut off by a fault at the Joyita Hills and farther south, along the prolongation of the east side of the Joyita uplift. A heavy covering by Santa Fe and later deposits in and south of T. 1 S. hides the structural relations.

Part of the valley is floored with sand and gravel, but ridges and slopes show Triassic and Cretaceous rocks along its center, and the outcrop of the Cretaceous widens greatly in the southern part of T. 1 N., R. 2 E. The structure of the principal features of the valley and adjoining ridges is shown in section 1 in figure 32. The Mesa del Yeso, a prominent butte of the Chupadera formation, rising in the center of the area, is shown in Plate XLV, A.

Taylor coal basin.—The Cretaceous rocks occupy a trough of considerable extent along the valley of Taylor Creek and the adjoining slopes. As shown in section 2, figure 32, they lie in a regular succession on red shales of Triassic age and dip at low angles to the west. To the south they are overlain by a thick mass of Tertiary igneous rocks, in places at least with an intervening conglomerate (Eocene?), which is well exposed northwest of the Cox ranch and west of the old coal pit 4 miles north of Taylor's ranch. This basin is cut off by a fault on its west side. In the higher beds near this fault there is a thin coal bed which has been prospected at several places. Probably this basin underlies a wide area of the Jornada del Muerto south of Taylor's ranch, but owing to the cover of sand and gravel and the absence of borings nothing is known of its character or relations in that area.

Prairie Spring anticline.—Rising from the Jornada del Muerto near Prairie Spring is an anticline which is expressed in the wide area of ridges of limestone and other rocks of the Chupadera formation extending to the mesas east of Rayo and beyond. In the center of this area, or near the middle of T. 2 S., R. 4 E., the red Abo sandstone is exposed for about a square mile along the axis of the anticline. The line of ridges east of the old auto road in that vicinity consists of limestone of the Chupadera formation dipping eastward into the basin of Arroyo Chupadero. The Sierra del Venado consists of the same limestones dipping west on the west side of the axis. Between these limestone ridges is a wide area of lower beds of the Chupadera formation.

Just west of Prairie Spring is a small local anticline or elongated dome on the west slope of the main anticline. It is shown by limestone of the Chupadera formation dipping on all sides below red shale of Triassic age. The spring is on the southwest end of this minor uplift.

A few other local irregularities were noted, but the details of structure were not ascertained. One remarkable local twist of the strata is exposed under the edge of the lava cap from Pyramid Crater, an old cone in the southwestern part of T. 2 S., R. 4 E. The beds are red sandstone and gypsum in the lower part of the Chupadera formation and evidently were contorted before the extrusion of the lava, which lies on a smooth plain.

Basin of Arroyo Chupadero.—The valley of Arroyo Chupadero is in a broad syncline (see section 2, fig. 32), which is a northern extension of the basin of the Jornada del Muerto. It rises to the north and is lost in the tablelands of southern Torrance County. The sides are broad outcrops of the Chupadera formation, and in the center, in Tps. 2 and 3 S., are red shales of Triassic age, largely covered by dune sand. In the center of T. 4 S., R. 4 E., the overlying Cretaceous strata appear, cut by some igneous intrusive rocks. Farther south are the wide sandy flats of the Jornada del Muerto.

Oscura anticline.—The prominent anticline which has produced Oscura Mountain extends far north of the northern termination of the mountains, probably to the Torrance-Socorro County line. The limestones of the Magdalena group pitch down rapidly in the northern part of T. 5 S., R. 6 E., and there is considerable faulting for some distance in the southwest corner of the township. Northward for 8 or 9 miles there is a broad anticline of the Abo sandstone flanked on both sides by the Chupadera formation. On the west side of the axis this formation constitutes ridges of moderate prominence, and on the east it constitutes the western slope of Chupadera Mesa. The dips are low, especially those on the east side. Near the center of T. 4 S., R. 6 E., the Abo sandstone pitches down to the north, and for 15 miles or more the uplift is expressed in Chupadera beds. The west limb of the anticline, where the dips are mostly from 5° to 10°, is marked by a north-south ridge of the limestones of the Chupadera formation. The dips on the east side are very low, and, as shown in section 2, figure 32, the limestones cap Chupadera Mesa. In general the anticline is fairly regular, but there are a few local irregularities. One of the most notable of these is a subordinate syncline and anticline with steep dips in and near the western part of T. 4 S. and the northwestern part of T. 3 S., R. 7 E.

Joyita Hills.—The Joyita Hills, which lie mostly in T. 1 N., R. 1 E., present a prominent anticline with pre-Cambrian granite exposed for a distance of about 3 miles along the center of its north-south course. Some of the features are shown in section 1, figure 32.

At the north end of the area the limestone of the Magdalena group is exposed, pitching down into the Abo sandstone, but at the south the relations are hidden by sand and gravel. On the east there is a broad belt of the Tertiary igneous rocks, which overlap on the granite unless, perhaps, there is a separating fault. The cross section in figure 33 shows some of the local details of structure.

The central ridge of granite is the highest topographic feature, and next west of it are slopes of limestone of the Magdalena group. A fault separates this limestone from granite. The red sandstone of the Abo formation, about 800 feet thick, forms a line of ridges or

knobs, just west of which are soft beds of the lower member of the Chupadera formation. These lower beds comprise 400 feet of reddish shales and soft red sandstones with some included limestone beds but no gypsum. Next above are soft red sandstones that grade up into massive gray sandstone, mostly hard, with one or two thin beds of limestone. This sandstone is overlain by limestone, the usual top member of the Chupadera formation. These upper sandstones and limestones, about 700 feet thick in all, constitute a line of ridges and knobs of considerable prominence extending all along the west side of the uplift. The Abo sandstone, shown at the left end of the section in figure 33, is in an uplifted block, which crops out only for a short distance and west of which are agglomerate, a bed of limestone conglomerate, and igneous rocks, all of Tertiary age.

On its east side the granite ridge is flanked by limestone of the Magdalena group, dipping steeply to the east. To the south these rocks show only in places, as the Tertiary igneous succession extends to the foot of the ridge, but to the north the limestone area widens

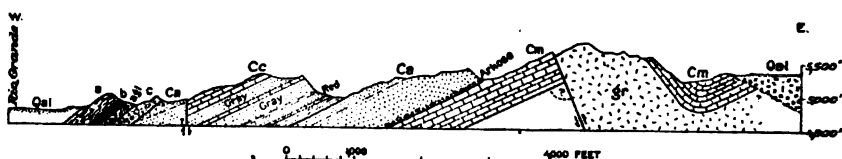


FIGURE 33.—Sketch section across the Joyita Hills, in T. 1 N., R. 1 E., Socorro County, N. Mex. Qal, Alluvium; a, andesite; b, basalt; agl, agglomerate; c, conglomerate; Cc, Chupadera formation; Ca, Abo sandstone; Cm, Magdalena group; gr, granite; l, lava, etc.

and reveals a pitching anticline. As the anticline pitches down to the north the limestone area widens, and it passes across the end of the uplift, as shown in Plate XLIII (p. 234). In this locality a deep canyon cut by a small arroyo reveals the limestone of the Magdalena group overthrust locally upon the red Abo sandstone, apparently by an extension of the fault shown to the right of the center of the section in figure 33. The limestone dips to the north and northwest, and the Abo sandstone to the west. The limestone extends north to Arroyo Cibola, where it pitches below the Abo sandstone, and this in turn is covered by sand, gravel, and the Tertiary igneous succession. There is no evidence of its extension in Agua Torres, and the isolated knob of granite 6 miles east of La Joya is due to a separate uplift.

Socorro and Lemitar mountains.—The Socorro and Lemitar mountains are parts of a westward-dipping succession of Tertiary igneous rocks on a platform of limestone of the Magdalena group underlain by pre-Cambrian rocks. The pre-Cambrian is exposed in a very small area low in the east slope of the Socorro Mountains, but granite is a prominent feature for 6 miles along the east slope of the Lemitar Mountains.

East of these mountains are the long sand and gravel covered slopes extending to the Rio Grande and in part underlain by tilted sandstones, etc., of the Santa Fe formation, which are well exposed near the north end of the Lemitar Mountains. To the west, as well as on the north and south ends of the range, lies a thick body of the Tertiary igneous rocks, which extend to the wide valley separating these ranges from the Magdalena Mountains. At the south end of the Socorro Mountains is a deposit of fuller's earth overlain by a sheet of basalt.

On account of the eastward-dipping limestone on the east side of these ridges, it is believed that they are of anticlinal structure throughout and that probably under the plain east of them there is a regular succession of Abo, Chupadera, Triassic, and Cretaceous rocks in a syncline. Ladrones Peak is on a northern continuation of the anticlinal axis. There is no evidence that the mountains are fault blocks, and the only fault noted is in the middle of the Lemitar Mountains, where the displacement is 500 feet or more, with the drop on the east side.

NACIMIENTO UPLIFT.

GENERAL RELATIONS.

In the north-central part of Sandoval County there is a prominent arch which gives rise to the Nacimiento Range and San Pedro Mountain. The beds are uplifted so high that in the central portions of the ridges the pre-Cambrian granites and schists appear. On the west side of this uplift the strata are upturned very steeply, constituting the east or southeast margin of the wide San Juan Basin. (See Pl. XLV, *B*, p. 237.) On the east side the dips are gentler, and limestones of the Magdalena group and overlying red shales and sandstones are spread out considerably and pass under the great pile of volcanic materials of the Valle Grande eruptions. The principal structural features are shown in figure 34.

STRATIGRAPHY.

The rocks exposed in these mountains are granites and schists; limestones and sandstones of the Magdalena group; and red shales and gray sandstones of the Permian and Triassic, which extend across the range in a depression of the anticline east of Senorito. Overlying strata as high as coal measures of the Mesaverde formation and early Tertiary deposits extend along the west slope of the mountains. The limestones on the east slope of the Sierra Nacimiento are extensively exposed in the deep canyons of the Rio de la Vaca and Jemez Creek, and on the intervening high mesas there is an extensive thick capping of tuffs and lavas of the Valle Grande volcanic area.

LOCAL STRUCTURE.

A short distance north of Jemez Springs a local anticline brings up the entire thickness of the Magdalena group, and the underlying granites are exposed in a small area in the bottom of the canyon. As the conditions in this area appear to be unfavorable for oil or gas, the minor details of flexure and faulting need not be presented here. At the south end of the mountains, however, south of Rio Salado, the strata pitch down, and although a profound fault cuts the east side of the uplift the arch is continued far southward in the Cretaceous

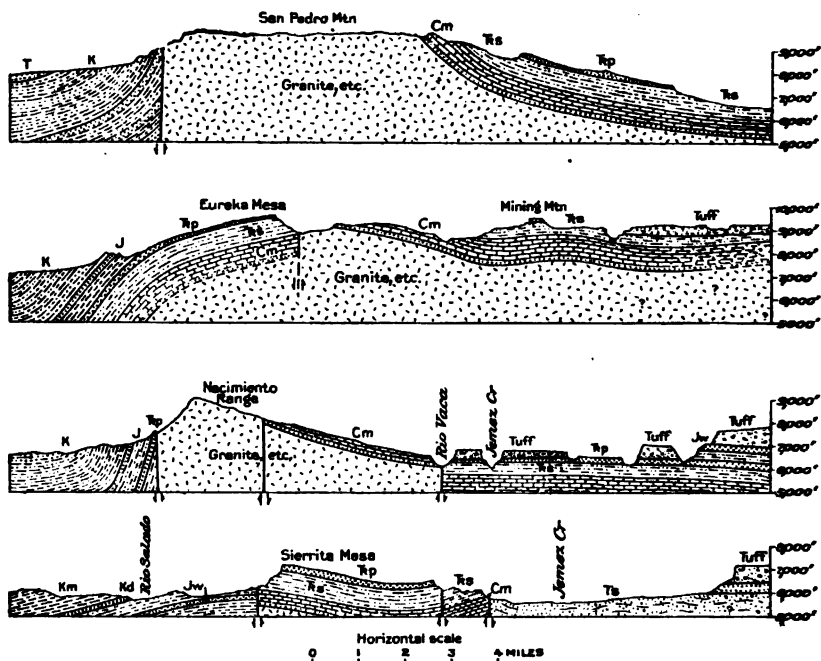


FIGURE 34.—Sections across San Pedro Mountain and the Nacimiento Range, in Sandoval and Rio Arriba counties, N. Mex. T, Tertiary; Ts, Santa Fe formation; K, Cretaceous; J, Jurassic; Jw, Wingate sandstone; Tp, Poleo sandstone; Ts, red shale; Cm, Magdalena group.

strata. This anticline is well exhibited through R. 1 W., from T. 15 N. to T. 13 N., and appears to extend still farther southwest, but the geology of the district has not been explored.

CHAMA BASIN.

GENERAL RELATIONS.

In the region above Abiquiu Rio Chama flows in canyons and broad valleys cut in a wide plateau on the northeast flank of a northern extension of the Nacimiento uplift. Above El Vado for many miles there is a broad valley in the Cretaceous shales, but below that place the Dakota sandstone is deeply trenched and

finally the underlying "Red Beds" are widely bared. In the greater part of the area the strata dip at very low angles; to the west they descend steeply into the San Juan Basin, and to the east they are cut off by faults and a steep uplift which brings up the pre-Cambrian

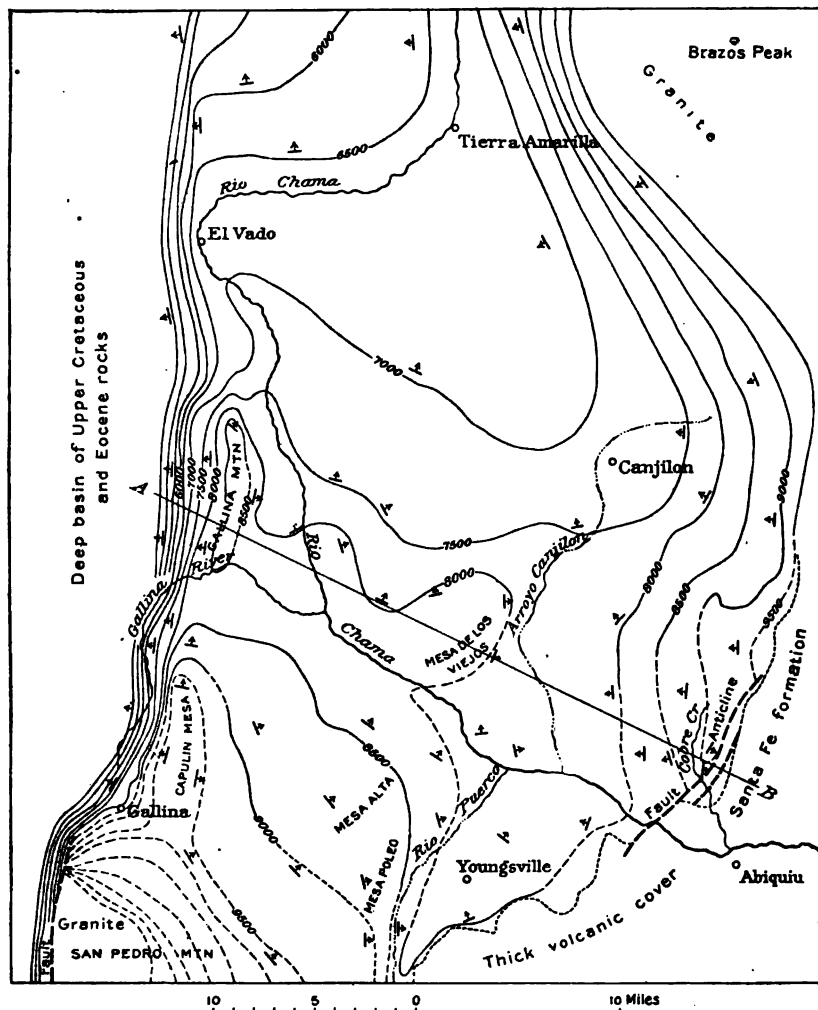


FIGURE 35.—Map showing structure in part of Rio Arriba County, N. Mex. Represented by contour lines at the top of the Dakota sandstone. Broken lines indicate areas from which the Dakota sandstone has been eroded. A-B, Line of section shown in figure 36.

crystalline rocks in the Brazos Peak district. Some of the broader structural features are shown by contours in figure 35, and the cross section, figure 36, shows the relations in the plateaus southwest of Canjilon, from T. 26 N., R. 1 W., to a point not far north of Abiquiu.

STRATIGRAPHY.

The principal formations in the Rio Chama basin are given in the following table:

Formations in southeastern part of Rio Arriba County, N. Mex.

Age.	Group and formation.	Characteristics.	Thickness (feet).
Upper Cretaceous.	Mesaverde formation.	Sandstone and shale, with coal beds.	900
	Mancos shale.	Shale and sandstone.	500-1,000
	Dakota sandstone.	Sandstone, massive, hard, gray to buff.	150-250
Cretaceous (?).	Morrison formation.	Shale, massive, greenish gray, buff, maroon; some sandstone.	100-180
Jurassic.	Navajo (?) sandstone.	Sandstone, chocolate-brown.	150
	Todilto formation.	Gypsum member. Limestone in thin layers, locally very sandy.	60 4-12
	Wingate sandstone.	Sandstone, very massive, fine grained; red below, white and buff at top.	200
Triassic.	Chinle (?) formation.	Red shale.	250
	Poleo sandstone.	Sandstone; maker of prominent ridges, plateaus, and cliffs.	50-150
Permian (?).		Red shale and red and brown sandstone.	250-550
Pennsylvanian.	Magdalena group.	Limestone mainly; sandstone at base and top.	60-450
Pre-Cambrian.		Granite.	

Of the sandstones in the region east of the Mesaverde ridge those which possibly contain oil if oil is present in this area are the Dakota, which lies at moderate depth in the Chama Valley above El Vado; the Navajo, 100 to 180 feet below the Dakota; the Wingate; the Poleo; and some sandstones in the Magdalena group. The Navajo (?) sandstone is in the midst of a series poor in carbonaceous sediments. The Poleo and Magdalena sandstones are at considerable depth below the valley in the El Vado-Amarillo region, but they crop out toward the south, the Magdalena rocks being exposed on the slopes of the San Pedro Mountains.

LOCAL STRUCTURE.

As shown in figure 35, part of the area is a flat-bottomed synclinal basin, and although doubtless there are local domes and anticlines in this basin surveys have not been sufficiently detailed to locate them. Gallina Mountain and Capulin Mesa are anticlines or elongated domes of considerable prominence, but they are to be regarded as northern extensions of the Nacimiento uplift. They will in due course probably receive the attention of the wildcat driller. Care, however, should first be taken to ascertain whether the carbonization of the carbonaceous debris has advanced so far as to preclude the survival of oil in the formations in which the oil is sought.

The Cobre Creek uplift, which lies east of the fault shown in figure 35, is an anticline or irregular dome bringing up the lower red beds and cut by several faults. The details of its structure were not determined, but the main features are shown in figure 36.

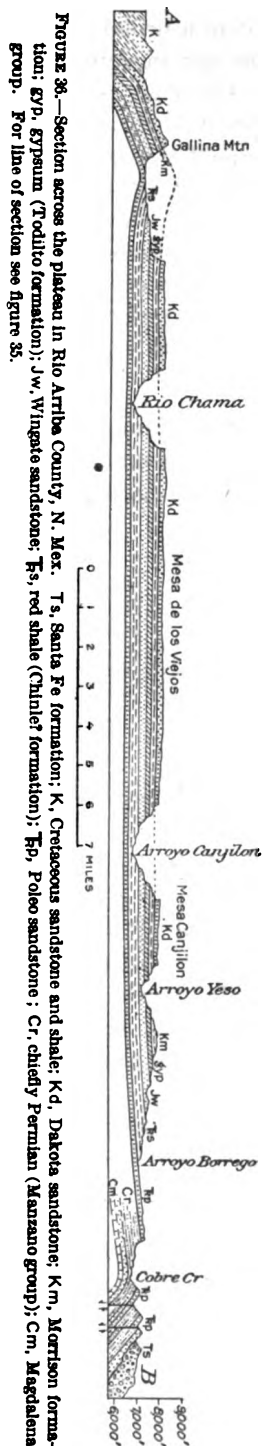
VALLE GRANDE AREA.

The Valle Grande Mountains, in the northeast corner of Sandoval County, attain an altitude of 11,200 feet in Redonda Peak. They consist of late Tertiary volcanic flows and tuffs which extend far down the slopes in every direction, reaching the level of the Rio Grande in the White Rock Canyon, west of Santa Fe. This great cover of volcanic products, in places thousands of feet thick, completely hides all the structural relations of the sedimentary rocks in the northeast corner of Sandoval County and the southeastern part of Rio Arriba County. To judge from the structure in the Jemez River basin, to the north, and the relations on the east slope of the Nacimiento uplift, it is not unlikely that the region is underlain by sedimentary rocks ranging from Cretaceous to Pennsylvanian in age, but the distribution and structure of these rocks can not be ascertained. It is probable also that many of the rocks have been greatly altered by heat and heated waters, so that if they ever did contain oil or gas most if not all of those products would have been destroyed or dissipated.

SAN JUAN BASIN.

GENERAL RELATIONS.

Most of the northwestern part of New Mexico consists of a broad, shallow basin occupied by a thick sedimentary succession including a widespread deposit of Eocene sandstones and clays. The Eocene beds constitute the surface in the western half of Rio Arriba County and most of the eastern part of San Juan County; the Mesaverde and overlying later Cretaceous sandstones and coal measures crop



out in a broad area to the west and south and in a narrow zone along the east margin of the basin. To the west is the Defiance anticline; to the east is the western limb of the Nacimient uplift, steeply upturned for most of its course; and to the south is the broad anticline of the Zuni Mountain uplift. (See fig. 39, p. 255.) In the wide basin area the strata present very low dips, mostly 1° to 2° or even less, an inclination which is hardly perceptible to the eye. There is gradual deepening of the basin to the north. The general stratigraphic succession and relations are shown in figure 37, taken from Bauer's report²² on part of the basin. There is a finely developed dome with its apex in the north-central part of T. 15 N., R. 6 W.

OIL.

Petroleum is present in this general region, locally at least, as a small amount was found several years ago in relatively shallow wells at Seven Lakes, and oil seeps are reported near Baker's trading post

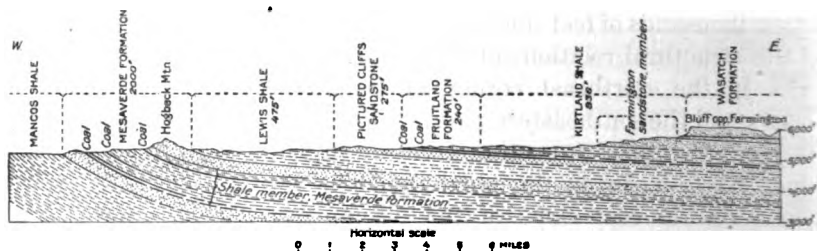


FIGURE 37.—Section along San Juan River from the Great Hogback to the bluff opposite Farmington, San Juan County, N. Mex. By C. M. Bauer.

and in Chaco Plateau. The first of these wells was one sunk for water in 1912 in sec. 18, T. 18 N., R. 10 W., in which considerable gas and oil were reported. Six other wells bored later found gas and some of them small amounts of oil at depths of 350 to 600 feet in Mesaverde beds. Whether or not this oil comes from a deep source and might be found in larger amounts at suitable depths where the strata are arched or domed can not be known until test borings are made.

It is generally believed that the structure in this region is not favorable for extensive reservoirs, but it is probable that detailed mapping of the structure will reveal somewhere in the region faint anticlines or domes in the Mancos and Mesaverde beds which may deserve testing.

A moderate amount of oil occurs in the sandstone of the Goodridge formation (probably equivalent to the Chupadera) in the canyon of San Juan River at Goodridge, Utah, 50 miles west of the northwest

²² Bauer, C. M., Stratigraphy of a part of the Chaco River valley: U. S. Geol. Survey Prof. Paper 27, p. 275, 1916.

corner of New Mexico. There are several productive wells, and the oil is of excellent quality. This formation lies far below the surface in the San Juan Basin, being probably almost 3,000 feet below at Ship Rock post office, 4,500 feet at Farmington, and 4,000 feet at Seven Lakes, but it comes to the surface in the Zuni Mountains.

It is claimed also that oil was found in some of the deep borings near Farmington, Fruitland, and Flora Vista.

LOCAL STRUCTURE.

Although the rocks in the greater part of the San Juan Basin appear to dip regularly into a wide basin, there are doubtless many local irregularities and reversals of dip due to domes, anticlines, and terraces. Only a small portion of the great area has been surveyed with care, and in the central part there is a widespread covering of early Eocene deposits, which conceal the structure of the underlying Cretaceous rocks. Figure 38 shows some structural features in the southeastern part of the basin.

One of the most notable structural irregularities in this area is the dome in Tps. 15 and 16 N., Rs. 6 and 7 W. The vertical uplift is more than 250 feet, and the dome brings to the surface the lower sandstone of the Mesaverde. The strata on the slopes have dips of 1° to 9° . Several faint domes occur farther west along the Mesaverde outcrop zone, and J. B. Reeside has noted one in the Navajo Indian Reservation about 12 miles west of Hunter's store.

According to Schrader²² the coal-bearing rocks in the upper part of the beds of Montana age are uplifted in a low dome on Hosta Butte.

The hogback ridge that forms a prominent topographic feature extending from southwest to northeast across the western part of San Juan County is due to steeply uplifted sandstones of the Mesaverde group. San Juan River cuts through it in a gap. In this ridge the strata dip steeply southeastward along a zone 45 miles long. According to plats made by L. S. Gillett, of the General Land Office, there is behind this hogback, in the southern part of the Southern Ute Reservation, an anticline of considerable prominence in which the Mancos shale is bared for 15 miles or more. Apparently this anticline flattens out in the area east of Ship Rock post office, for it has not been noted near San Juan River. The dips are 8° to 10° on the southeast side of the flexure and very low on the northwest side, where there are southward-facing cliffs of sandstone of the lower part of the Mesaverde group.

²² Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, p. 253, 1906.

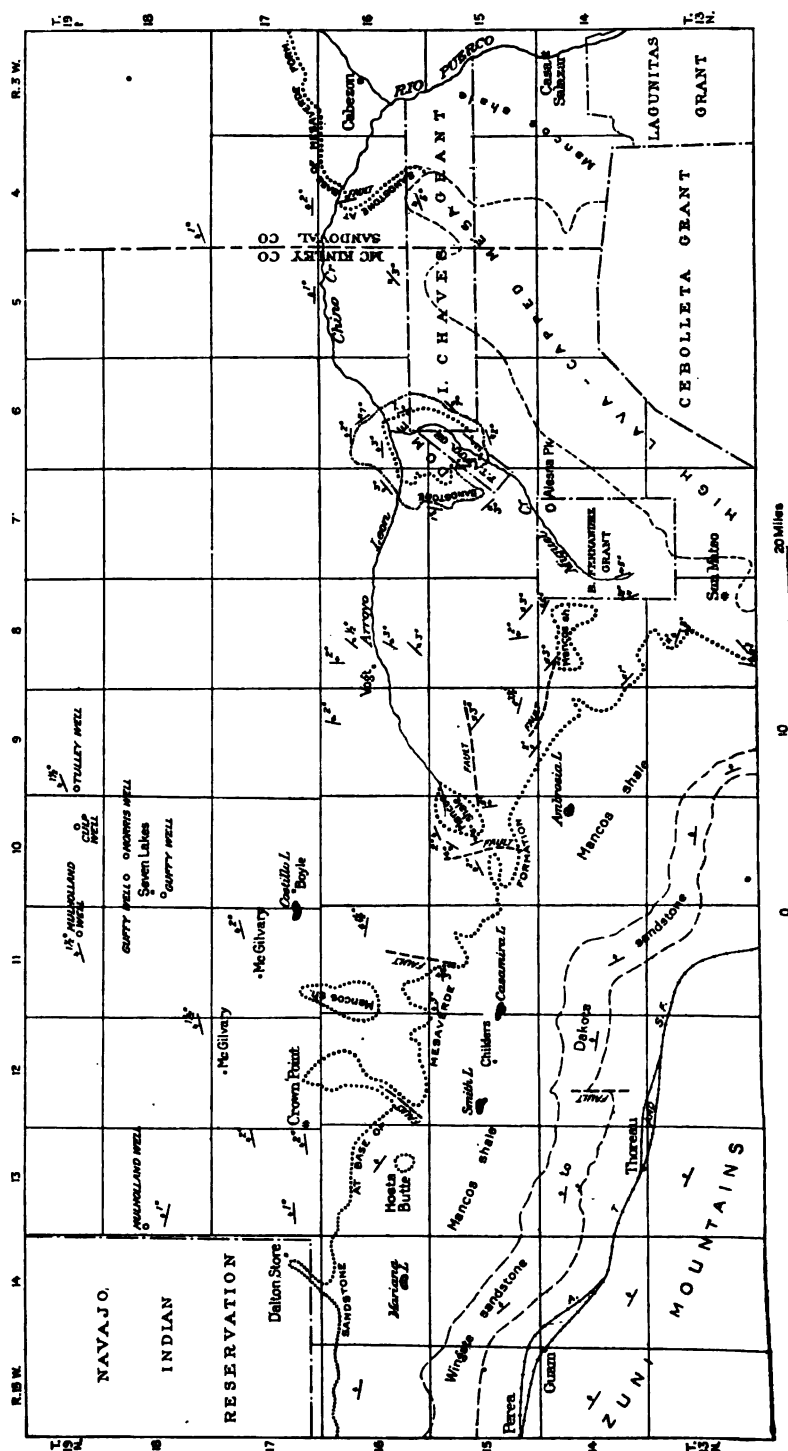


FIGURE 34.—Geologic sketch map of part of McKinley County, N. Mex., showing some structural features. Compiled mostly from unpublished plats by C. B. Barker and L. A. Gillett. Initial inspectors, General Land Office.

DEEP BORINGS.

Several deep holes have been bored for oil in the San Juan Basin. The deepest one was sunk in 1913 by the Farmington Oil & Gas Co. on the Blake farm, near Farmington, in sec. 15 (?), T. 29 N., R. 13 W. The record was as follows:

Record of deep well in sec. 15 (?), T. 29 N., R. 13 W., near Farmington, N. Mex.

	Feet.
Soil and cobblestones.....	20
Sand.....	21
Sandy shale.....	31
Shale, light.....	215
Sand; gas.....	240
Shale, light.....	230
Sand, gray.....	285
Shale.....	320
Sand.....	325
Shale; gas.....	387
Sand; gas.....	394
Shale.....	425
Sand.....	432
Shale, light.....	582
Shale, brown; gas at 730 and 790 feet.....	797
Shale, dark.....	1, 075
Sand; gas.....	1, 160
Shale, light.....	1, 185
Sand.....	1, 220
Shale, brown.....	1, 370
Sand, gray.....	1, 375
Shale, brown.....	1, 710
Sand, dark.....	1, 780
Shale, sandy, light.....	1, 830
Shale, sandy, dark.....	1, 940
Sand, dark.....	1, 965
Shale, sandy, dark.....	2, 045
Sand, white, fine.....	2, 050
Shale, sandy; dark shells.....	2, 205
Sand, hard.....	2, 210
Shale, sandy; dark shells; salt water at 2,300 feet.....	2, 310
Sand, dark.....	2, 430
Sand, white.....	2, 435
Sand, dark gray.....	2, 495
Sand, white.....	2, 580
Sand, gray; coal at 2,620 and 2,640 feet.....	2, 610
Shale, sandy.....	2, 640
Sand, white, hard.....	2, 655
Coal.....	2, 658
Sand and shale; strong flow of water over top of casing.....	2, 678
Sand, red-brown; some oil (pit asphaltum or maltha).....	2, 685
Sand, gray, with specks of coal; water from well dark brown, cooler and less salty.....	2, 695
Sand, gray-white.....	2, 725
Coal and shale.....	2, 730
Shale, tough; water milky.	

It is suggested by Mr. Reeside, who kindly furnished the record, that the hole penetrated the Kirtland shale at 16 to 797 feet, the Fruitland formation at 797 to 1,075 feet, the Pictured Cliffs sandstone at 1,075 to 1,370 feet, the Lewis shale at 1,370 to 1,940 feet, the Cliff House sandstone (top formation of Mesaverde group) at 1,940 to 2,610 feet, and the Menefee (or middle formation of the Mesaverde group) at 2,610 to 2,730 feet, where the drill stuck.

A well in progress in sec. 2, T. 30 N., R. 12 W., was reported to have reached a depth of 2,900 feet in December, 1920. Some gas was reported in sands at 2,100 to 2,250 feet and at other horizons, and coal, one bed of which was 14 feet thick, between 1,700 and 2,085 feet.

A hole sunk in sec. 16, T. 30 N., R. 15 W., by the San Juan Basin Oil & Gas Co. to a depth of 2,080 feet had the following record:

Record of deep well in sec. 16, T. 30 N., R. 15 W., about 5 miles north of Fruitland, N. Mex.

	Feet.
Record lost; thin coal at 84 feet.....	0-400
Blue mud.....	450
Shale, sandy.....	470
Shale, blue.....	524
Sand; showing of oil.....	525
Shale, blue.....	670
Lime shell.....	672
Shale, blue.....	680
Lime, shell.....	681
Shale, blue.....	706
Limestone.....	710
Lime shells and blue shales.....	810
Shale, brown.....	840
Shale and lime shells.....	965
Sand; salt water.....	973
Shale, sandy, brown.....	988
Lime shells and blue shales.....	1,038
Softer shales and lime shells.....	1,158
Shale, blue.....	1,208
Shale, blue, with lime streaks.....	1,403
Light shale and lime shells.....	1,530
Shale, brown.....	1,580
Hard lime.....	1,586
Sand; salt water.....	1,598
Shale, blue, with lime streaks.....	1,615
Hard lime.....	1,625
Sand; good showing of oil.....	1,640
Sand; salt water.....	1,665
Shale, sandy.....	1,690
Sand; salt water.....	1,720
Shale, gray, with strata of lime.....	1,900
Shale with lime streaks.....	1,980
Lime with burnt formation.....	2,010
Shale, black, with lime streaks.....	2,070
Hard sandrock with artesian salt water, which ran over casing in small stream.....	2,080

According to Mr. Reeside, who kindly furnished the log, the hole began in the Fruitland formation, penetrated the Pictured Cliffs sandstone and Lewis shale from 84 to 965 feet and the Cliff House sandstone from 965 to 1,580 feet, and ended in the Menefee formation.

Another hole 1,719 feet deep, sunk by the same company in the adjoining sec. 21, is reported to have struck considerable oil, but owing to breaking of tools the well was abandoned. It is said that the well passed through a thin bed of coal with salt water at 83 feet and found fresh water at 113 feet and at 740 feet. Shale, presumably the Lewis shale, began at 200 feet, and the first indications of oil were at 1,715 feet. These two holes near the center of T. 30 N., R. 15 W., appear to have been in some small anticlinal crumples on the slope of the main hogback monocline, and unfortunately they did not test all the Mesaverde strata.

A hole in sec. 16, T. 30 N., R. 12 W., 3 miles northwest of Flora Vista, reached a depth of 1,512 feet in July, 1920, and reported a small amount of oil. It penetrated the Wasatch formation and the Kirtland shale and Fruitland formation. The Mesaverde, according to Bauer's section, is about 400 feet below. The beds dip to the east at a low angle, averaging about 1° .

Another test hole 2 miles to the west, in sec. 18, about 200 feet higher, was 890 feet deep and is reported to have found a small amount of oil.

A well 1,111 feet deep at the Pueblo Bonito School, in sec. 30, T. 17 N., R. 12 W., penetrated alternating sandstone and shale with four thin beds of coal near 700 feet.³⁴ Another well, 1,205 feet deep,³⁴ 5 miles to the northwest, in sec. 10, T. 17 N., R. 13 W., penetrated shale and sandstone. Both of these holes were in the Mesaverde and Mancos formations. A third hole in the same general vicinity, in sec. 12, T. 18 N., R. 12 W., is 1,030 feet deep and yields a flow of water.

Several wells have been bored for oil recently in the Seven Lakes district. One in sec. 31, T. 18 N., R. 9 W., reached a depth of 800 feet without success. Below 65 feet continuous sandstone was reported. A 390-foot hole in sec. 16, T. 17 N., R. 11 W., penetrated sand and shale with thin layers of lignite.

A well in the center of sec. 18, T. 18 N., R. 13 W., 35 miles north-east of Gallup, had the following log, according to Mr. Gus Mulholland, of Gallup:

Log of boring 10 miles northwest of Crown Point, McKinley County, N. Mex.

	Feet.
Sand and mud.....	0-80
Sandstone, white.....	80-240
Lime shell.....	240-245
Shale.....	245-475

³⁴ For records see Gregory, H. E., *The Navajo country*: U. S. Geol. Survey Water-Supply Paper 380, p. 181, 1916.

	Feet.
Sandstone, gray; water alkaline	475-525
Lime shell.....	525-535
Sandstone, hard, gray.....	535-585
Shale.....	585-635
Sandstone.....	635-655
Coal and shale.....	655-665
Sandstone, white.....	665-700
Shale, blue.....	700-725
Sandstone.....	725-785
Lime shell.....	785-805
Sandstone.....	805-845
Shale.....	845-1,000
Sandstone; good water.....	1,000-1,030
Shale, sandy.....	1,030-1,050
Sandstone, gray.....	1,050-1,090
Shale.....	1,090-1,120
Sandstone, with good flow of water	1,120-1,200
Lime shell.....	1,200-1,210
Sandstone, hard, gray.....	1,210-1,320
Sandstone; flow of good water at top	1,320-1,400
Shale, hard, brown.....	1,400-1,520
Shale and fire clay; small flow of oil, some gas.....	1,520-1,540

This well penetrated the Mesaverde strata and entered the shales of the Mancos group.

Record of artesian well 9 miles southeast of Tohachi, N. Mex.

	Feet.
Sand and clay.....	0-80
Fine sand.....	80-102
Shale.....	102-104
Tough blue clay.....	104-112
Shale and shallow layers of rock.....	112-174
Light-gray sandstone, hard.....	174-186
Shale and slate.....	186-192
Light-gray sandstone, hard.....	192-225
Shale.....	225-234
Sandstone.....	234-236
Shale.....	236-242
Slate, hard.....	242-250
Sandstone.....	250-262
Shale.....	262-285
Sandstone, extraordinarily hard.....	285-288
Sandrock, loose.....	288-298
Coal; water rose within 28 feet of surface.....	298-299
Shale, tough and sticky.....	299-332
Shale.....	332-340
Sandstone.....	340-342
Slate, very hard.....	342-356
Sandstone.....	356-357
Shale.....	357-398
Sandstone; water rose within 20 feet of surface.....	398-402
Shale.....	402-422
Shale, sandstone, and coal.....	422-426

	Feet.
Gallup fire clay.....	426-446
Rock, very hard, dark, carrying mineral.....	446-454
Light-gray sandstone.....	454-620
Fire clay.....	620-622
Light-gray sandstone.....	622-684
Dark-brown sandstone.....	684-702
Fire clay.....	702-722
Light-gray sandstone.....	722-742
Fire clay.....	742-753
Light-gray sandstone.....	753-774
Fire clay.....	774-800
Sandstone; thin layer of coal.....	800-816
Fire clay.....	816-906
Light-gray sandstone; water over casing, 90 gallons an hour.....	906-943
Coal.....	943-946
Light-gray sandstone.....	946-949
Fire clay.....	949-955
Dark close-grained rock, hard.....	955-964
Fire clay.....	964-988
Shale.....	988-1,001
Close-grained sandrock, hard.....	1,001-1,018
Fire clay, very tough and sticky.....	1,018-1,035
Close-grained sandrock, very hard.....	1,035-1,050
Light-yellow sandrock; water flows 300 gallons an hour.....	1,050-1,058
Light-gray sandrock.....	1,058-1,082
Light-yellow sandrock; well flows 2,500 gallons an hour.....	1,082-1,094
Light-gray sandrock; well flows 6,000 gallons an hour.....	1,094-1,108
Shale.....	1,108-1,150

ZUNI MOUNTAINS.

GENERAL RELATIONS.

The Zuni Mountains, in McKinley and Valencia counties, are due to hard rocks uplifted by an extensive anticline or elongated dome. This uplift has steep dips on its west side, where the strata pass under the Zuni-Gallup coal basin (see Pl. XLVII, A), and very gentle dips on the north and northwest sides into the San Juan Basin (see Pls. XLVI, A; XLVII, B). Toward the southeast the flexure flattens into a broad monocline extending under the Cebolleta Mesa. The sections in figure 40 show the principal structural features of the Zuni Mountain uplift, and some general relations are shown in figure 39. As is shown in the cross sections, the uplift is relatively regular, but the rate of dip varies from place to place, and there is considerable faulting in part of the area. The pre-Cambrian granite is exposed by erosion in three areas in the center of the uplift. Well-marked subordinate structural features such as local or minor domes and anticlines are rare, although all of the area has not been closely scrutinized for those features. West of Grant there are a number of minor domes near the foot of the limestone slopes, and it is possible that in the wide shale valley extending from Bluewater to the area northwest of Wingate there may be some local uplifts.

STRATIGRAPHY.

The strata exposed in the Zuni Mountain uplift comprise formations from the base of the Abo sandstone (Permian) to the coal measures of the Upper Cretaceous.

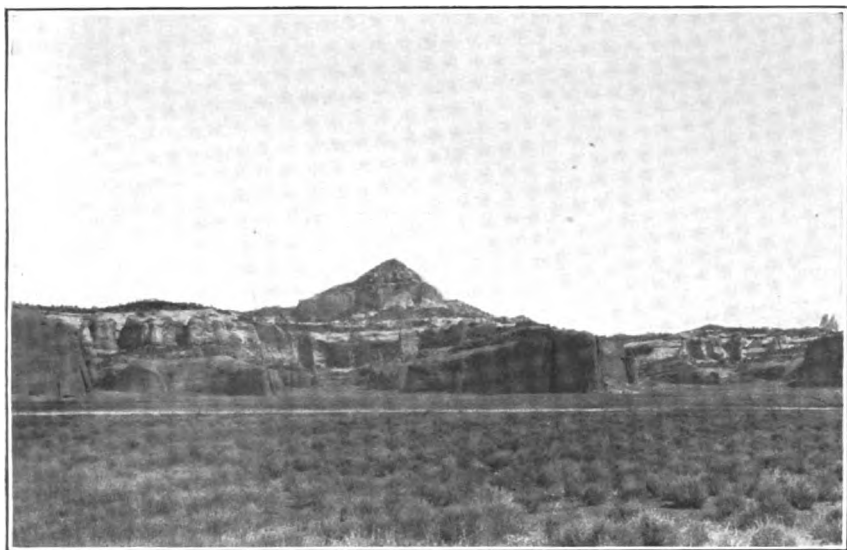
Formations in the Zuni Mountain uplift.

Age.	Group and formation.		Characteristics.	Approximate average thickness (feet).
Upper Cretaceous.	Mesaverde formation.		Sandstone with coal beds.	1,000
	Mancos shale.		Shales and sandstones; coal in upper part.	750
	Dakota sandstone.		Sandstones, massive, gray, hard.	120-250
Cretaceous (?)	McElmo formation.		Sandstone and sandy shale, gray-greenish to maroon.	150
Jurassic.	Navajo sandstone.		Sandstone, massive, gray to pink.	300-650
	Todilto limestone.		Limestone, mostly very thin bedded.	0-20
	Wingate sandstone.		Sandstone, fine-grained, massive, pink, hard, making high cliffs on north side, soft on south side of uplift.	300-400
Triassic.	Chinle formation.		Shale, red to gray, limestone concretions.	850
	Shinarump conglomerate.		Sandstone, gray to buff, locally conglomeratic.	20-60
	Moenkopi formation.		Shale, mostly sandy and red.	500-850
Permian.	Mazano group.	Chupadera formation.	Limestone and hard gray sandstone above, soft red sandstone below.	500
		Abo sandstone.	Brown-red slabby sandstone and sandy shale, with locally basal limestone and sandstone.	600-700
Pre-Cambrian.			Granite, etc.	

The sandstones in the Chupadera formation and the Shinarump conglomerate can be reached by borings of moderate depth in the valleys adjoining the uplift. These sandstones, however, lie very deep in the basin west of the uplift and under the valley of Mancos shale to the north.

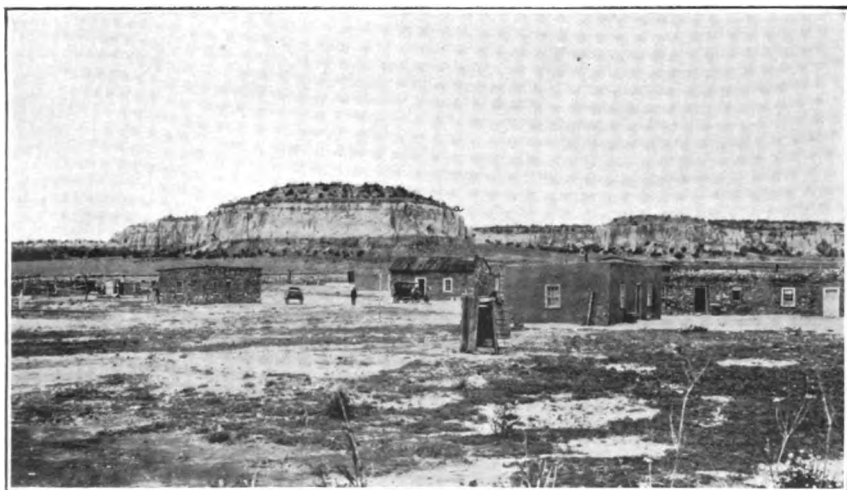
DEEP BORINGS.

Holes of considerable depth have been bored for water at several points along the Atchison, Topeka & Santa Fe Railway between Bluewater and Gallup. At Gallup, which is in the basin west of the uplift, the borings obtain artesian water from the Dakota and over-



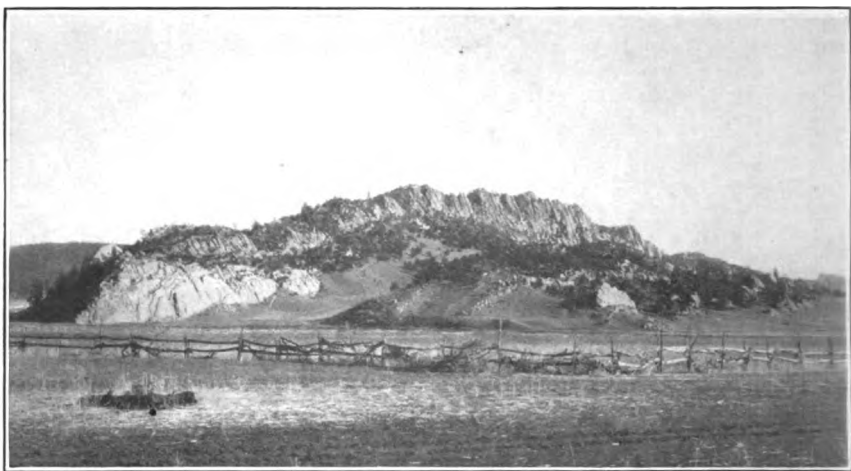
A. PYRAMID ROCK, 10 MILES EAST OF GALLUP, N. MEX.

Red cliffs of Wingate sandstone in foreground; Navajo sandstone and higher beds on ridge and pyramid.



**B. UPLIFT AT ATARQUE, SOUTHWESTERN VALENCIA COUNTY, N. MEX.,
LOOKING NORTHEAST.**

Dakota sandstone lying unconformably on Navajo sandstone.



A. WEST SLOPE OF ZUNI UPLIFT AT NUTRIA, N. MEX., LOOKING SOUTHEAST.
Navajo and Wingate sandstones.



B. NORTHWEST SLOPE OF ZUNI UPLIFT EAST OF GALLUP, N. MEX., LOOKING NORTH.
Dakota and overlying sandstones.

lying sandstones. None of these holes except possibly the wells at Gallup and Bluewater have been sunk in places where the structure would be favorable for oil accumulation, and, moreover, none of them

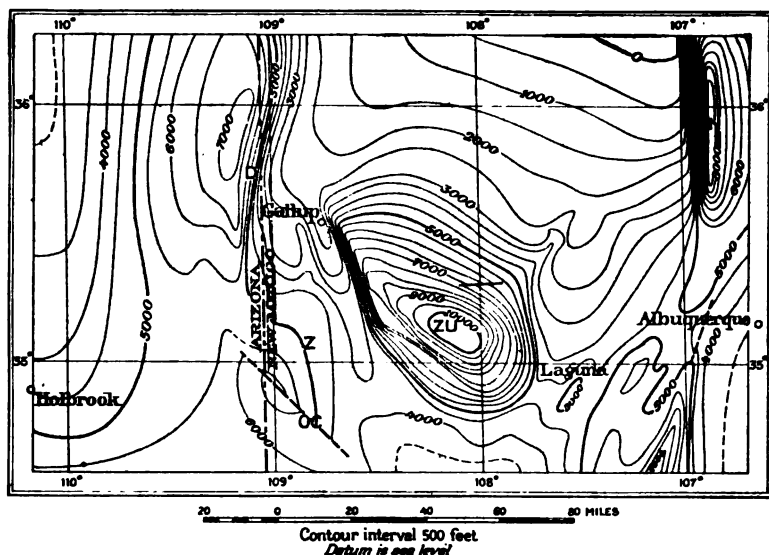


FIGURE 39.—Map showing structure of part of northwestern New Mexico. ZU, Zuni uplift; N, Nacimiento uplift; D, Defiance uplift; OC, Ojo Caliente uplift and fault; Z, Zuni. Contours represent top of Chupadera formation, which, however, is absent on the higher uplifts.

are sufficiently deep to reach the sandstones of the Chupadera formation. No traces of oil or gas were reported. The well at Bluewater had the following record:

Record of boring at Bluewater station, N. Mex.

	Feet.
Lava, two beds (?), with thin bed of tuff and red clay between.....	0-90
Clay, red.....	90-159
Clay, blue.....	159-260
Sandstone, gray, soft.....	260-263
Clay, blue.....	263-270
Sandstone, gray, hard above, red below.....	270-291
Limestone, hard, with hard dark sandstone at 439-447 feet.....	291-455
Sandstone, white; water in small amount.....	455-575
Sandstone, red; bad water.....	575-735

This hole passed through clays in the lower part of the Moenkopi formation to 291 feet, limestones and sandstones of the Chupadera formation to 575 feet, and lower red beds at the base of the Chupadera, possibly reaching the top beds of the Abo sandstone, to the bottom.

An artesian well at North Chaves, 707 feet deep, doubtless draws its supply of excellent water from the Shinarump conglomerate,

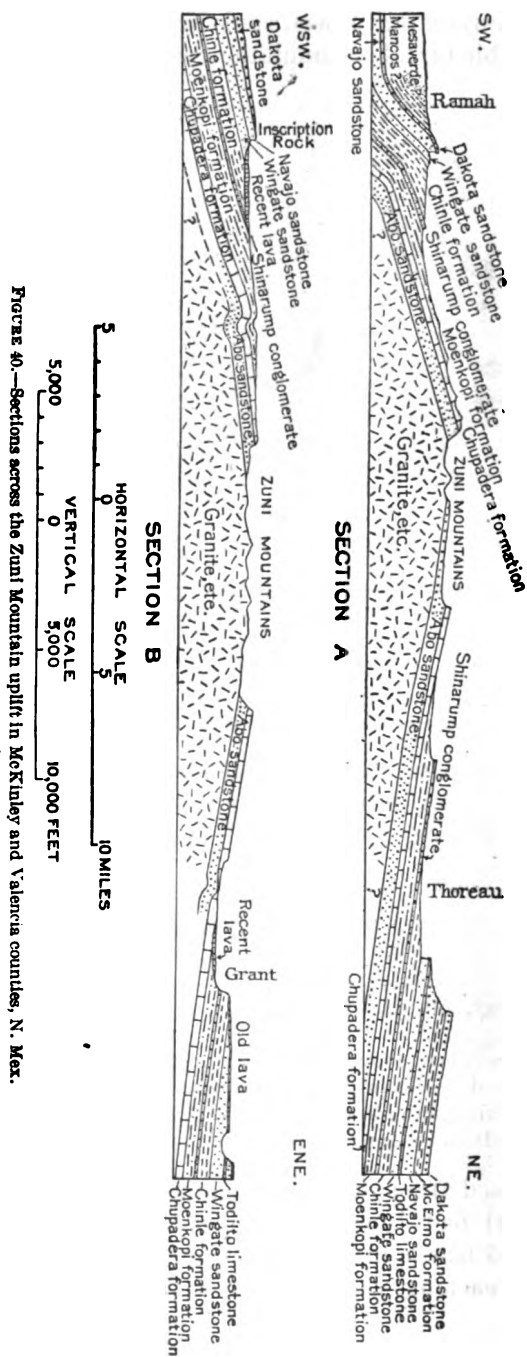


FIGURE 40.—Sections across the Zuni Mountain uplift in McKinley and Valencia counties, N. Mex.

which rises to the surface on the dip not far south of the railroad. The following record is given:

Record of well at North Chaves siding, McKinley County, N. Mex.

	Feet.
Clay, sand, and gravel.....	0-52
Sandstone, gray.....	52-195
Clay, red.....	195-530
Clay, blue.....	530-570
Sandstone, gray.....	570-595
Sand, black.....	595-600
Sandstone, gray.....	600-700

A 600-foot hole at Guam penetrated the following strata:

Record of boring at Guam, N. Mex.

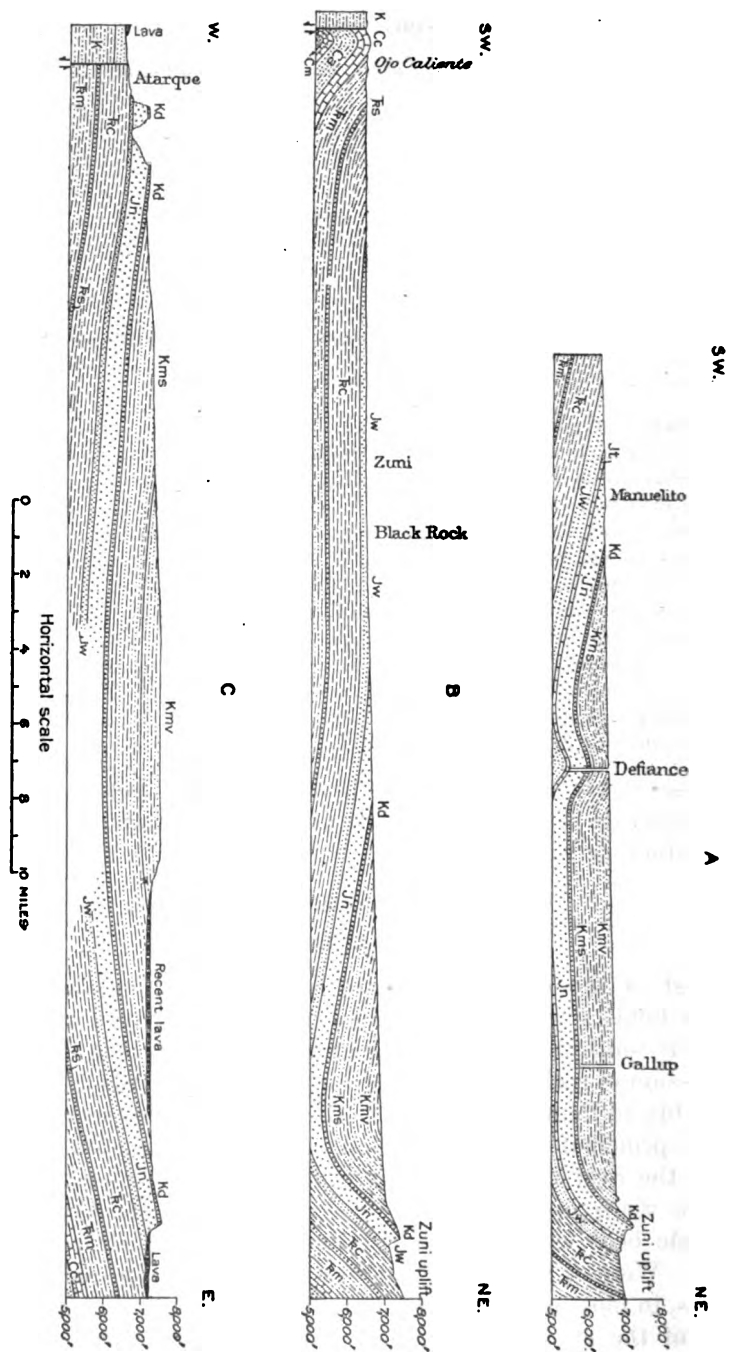
	Feet.
Sand, clay, and gravel.....	0-55
Sandy clay, with petrified wood at base.....	55-76
Shale, blue, compact.....	76-92
Sandstone, soft, white.....	92-103
Shale, red.....	103-108
Sandstone, red, hard.....	108-135
Shale, red.....	135-145
Sandstone and conglomerate; small supply of water.....	145-155
Sandstone, gray.....	155-210
Shale, blue, compact.....	210-410
Shale, soft.....	410-540
Sandstone, red, hard.....	540-560
Shale, red, hard.....	560-600

These strata are all in the Chinle formation, but the Shinarump conglomerate was not far below and no doubt would have yielded a satisfactory water supply.

GALLUP-ZUNI BASIN.

GENERAL RELATIONS.

West of the Zuni uplift there is a basin of considerable extent which holds a wide area of Cretaceous coal measures at Gallup and extends southward for 60 miles or more into Valencia County. The succession of rocks in this basin comprises strata from late Cretaceous probably to Pennsylvanian. As shown in the cross sections of figure 41 the principal structural features are the steep descent of the strata along the west side of the Zuni uplift; the wide, flat-bottomed basin to the west; and the gradual reappearance of the Cretaceous and Jurassic beds as the strata rise and the country drops toward the west. West of the axis of the basin the strata dip east at very low angles, in most places appearing to be practically horizontal. In this part of the area there are low domes and structural terraces, but only a few of the features of this character have been investigated.



STRATIGRAPHY.

The formations underlying the Gallup-Zuni Basin are set forth in the following table:

Formations in Gallup-Zuni Basin.

Age.	Group and formation.		Character.	Thickness (feet).
Upper Cretaceous.	Mesaverde formation.		Sandstones with coal beds.	1,000±
	Mancos shale.		Upper half sandstones and shales; lower half mostly shale.	900
	Dakota sandstone.		Sandstone, massive, gray to buff.	50-100
Jurassic.	Navajo sandstone.		Sandstone, gray to pink, massive.	450-600
	Todilto limestone.		Limestone, thin bedded.	15-25
	Wingate sandstone.		Sandstone, pink, massive and hard to north.	280-400
Triassic.	Chinle formation.		Shale, red, gray, and purple.	850-900
	Shinarump conglomerate.		Sandstone, partly conglomeratic.	50-80
	Moenkopi formation.		Shale, gray to red, part sandy; thickens to southwest.	500-900
Permian.	Manzano group.	Chupadera formation.	Limestone and gray sandstone.	800±
		Abo sandstone.	Brownish-red slabby sandstone.	800±
Pennsylvanian.	Magdalena group.		Limestone. (Probably present.)	(?)
Pre-Cambrian.			Granite, etc.	

These rocks present the same features that they have in other portions of western New Mexico. The Magdalena group is not exposed, but on account of the thickness of limestones of Pennsylvanian age farther west it is believed to be present. Sandstones texturally favorable for oil or gas, if these materials are present, are those in the Mesaverde, which is at or near the surface throughout, the Mancos, which is 600 feet or more deep in places, the Dakota sandstone, the Shinarump, and especially the massive gray sandstone in the Chupadera formation. The Dakota sandstone, however, is usually full of water.

LOCAL STRUCTURE.

A well-defined anticline or dome at Defiance switch, 8 miles west of Gallup, brings up the sandstone at the top of the Mancos shale in a small area. (See section A, fig. 41.) The extent of the flexure

was not determined. In 1918 a 1,155-foot hole was bored on this anticline by the Carter Oil Co., with the record given on page 261. There is a broad terrace or doming of the strata near Zuni pueblo. North of Zuni Buttes a prominent arch which extends to and beyond the valley of Whitewater Creek brings to the surface the Chinle formation in an area of moderate extent. In 1919 a test hole was bored near the crest of this anticline by the Carter Oil Co.; the strata penetrated are given on page 262.

A pronounced doming of the strata in the eastern part of Gallup is indicated by the altitude and relations of the coal measures. The vertical uplift is several hundred feet, but no precise measurements have been made. The dome pitches down to the north, and in the vicinity of the coal mines at Gibson it is also considerably faulted. The anticlinal structure appears to continue for some distance south of Gallup. The 1,112-foot artesian well at Gallup draws from the Dakota sandstone near the crest of this dome. This sandstone appears to have been reached at a depth of 940 feet.

In the vicinity of Ojo Caliente there is a well-marked anticlinal uplift, cut off on the west side by a fault, which brings the Mancos and Chupadera formations into contact, as shown in section B, figure 41. At the axis of this uplift a small area of the top limestone of the Chupadera formation is exposed. This uplift extends southeastward to Atarque, where it is exhibited in a low arch of the red Navajo sandstone. (See Pl. XLVI, B, p. 254.) Whether or not the fault extends as far southeast as this locality was not determined. The structural conditions at Atarque, Ojo Bonito, and Ojo Caliente appear to be favorable for the accumulation of oil or gas provided those materials are present in the strata. At all these points the strata that may prove to be oil bearing are sandstones in the Chupadera formation, which are at a very moderate depth, or sandstones or limestones of the Magdalena group, which may underlie the area. The Chupadera formation and the Magdalena group are separated by about 800 feet of the red sandstones of the Abo formation, which is not promising as a source of oil or gas.

DEEP BORINGS.

A few deep holes in the southern part of the basin have not revealed any evidence of oil or gas. A 1,112-foot well at Gallup furnishes a flow of excellent water from the Dakota sandstone. Its record is as follows:

Record of city artesian well at Gallup, N. Mex.

Upper part of Mancos shale:		Feet.
Wash.....		0-75
Sandstone.....		75-95
Shale.....		95-128
Sandstone.....		128-136
Shale.....		136-141

Lower part of Mancos shale:

	Feet.
Sandstone.....	141-195
Shale.....	195-225
Sandstone.....	225-296
Sandy shale.....	296-309
Shale.....	309-798
Sandstone and shale.....	798-814
Sandstone.....	814-855
Shale.....	855-908
Sandstone.....	908-912
Shale.....	912-940
Sandstone (Dakota), with 20 pounds pressure, 15-gallon flow.	940-1, 112

A 1,155-foot hole sunk on the anticline at Defiance switch, in the SW. $\frac{1}{4}$ sec. 29, T. 15 N., R. 19 W., 8 miles west of Gallup, found an artesian flow of water and ended in the upper part of the Navajo sandstone. If boring had continued 1,500 feet deeper the drill would have tested the Shinarump conglomerate. The sandstone in the Chupadera formation lies about 800 feet still deeper. This well was drilled in 1918 by the Carter Oil Co. The following record made by the driller was kindly supplied by the Atchison, Topeka & Santa Fe Railway Co.:

Record of boring at Defiance siding, McKinley County, N. Mex.

	Feet.
Soil.....	0-6
Quicksand.....	6-200
Shale.....	200-203
Sandstone, light.....	203-235
Sandstone, in part conglomeratic; water.....	235-251
Shale, blue.....	251-252
Sandstone, white; water.....	252-290
Shale, blue.....	290-295
Sandstone, light.....	295-330
Shale, light.....	330-380
Sand, light brown.....	380-385
Shale, blue.....	385-403
Sandstone, white; artesian flow.....	403-535
Shale, sandy.....	535-555
Sandstone.....	555-567
Sandstone, red.....	567-570
Sandstone, white.....	570-600
Sandy shale.....	600-765
Sandstone, white.....	765-885
Sandstone, gray; artesian flow at 1,030 feet, 25 gallons a minute.....	885-1, 125
Sandstone, pink, hard.....	1, 125-1, 155

It is difficult to recognize strata in this record, because the sandy component of the material has been exaggerated. Shales of the Mancos formation extend to a depth of 765 feet, where the Dakota sandstone was entered. Doubtless the Dakota extends to 885 feet, where the drill entered the Navajo sandstone. It is unfortunate

that this hole was not continued through the Wingate sandstone and underlying red beds to test lower strata—the Shinarump, Chupadera, and Abo.

Several deep holes have been sunk in the coal measures near Gibson and Clarkville, north of Gallup. One of these at the Heaton mine, 1 mile northeast of Gibson, was 1,033 feet deep, and one at Gibson was 935 feet deep. Both were in Mesaverde and Mancos beds.

The test well sunk by the Carter Oil Co. in 1919 in the SW. $\frac{1}{4}$ sec. 17, T. 11 N., R. 19 W., about 30 miles southwest of Gallup, reached a depth of 1,980 feet. The boring began not far below the top of the Chinle formation and was discontinued in the Abo sandstone. The following strata were reported by Mr. Nesselrode, the superintendent; the identifications of the formations are my own:

Record of well in the SW. $\frac{1}{4}$ sec. 17, T. 11 N., R. 19 W., N. Mex.

Chinle, Shinarump, and Moenkopi formations:		Feet.
Shale, all red.....		0-1, 006
Sandstone, gray to white.....		1, 006-1, 010
Shale, red.....		1, 010-1, 070
Chupadera formation:		
Limestone.....		1, 070-1, 100
Sandstone, gray.....		1, 100-1, 355
Shale, red.....		1, 355-1, 630
Abo sandstone:		
Limestone, very hard, some grit.....		1, 630-1, 650
Shale, red.....		1, 650-1, 980

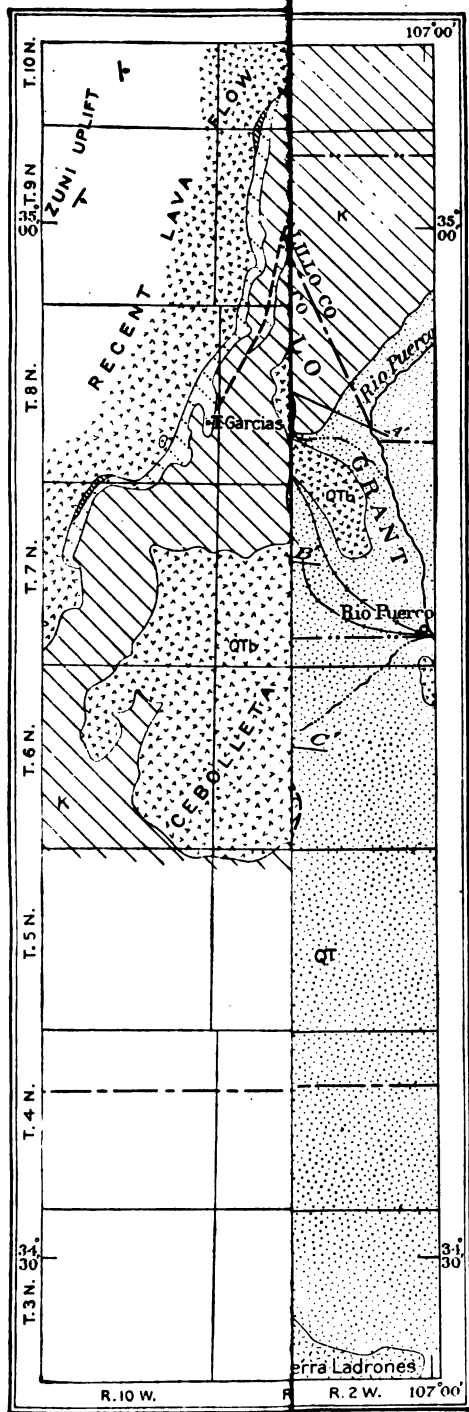
Boring was discontinued mainly because it was supposed that the hole had nearly reached the base of the sedimentary succession. The report that this hole reached granite is doubtless a mistake. It is likely that the Abo formation is at least 800 feet thick at this place, in view of the probable thickness from the Zuni Mountain uplift to the outcrops of corresponding strata in eastern Arizona, and that a considerable thickness of the underlying Magdalena is also present. The Magdalena is apparently absent in the Zuni Mountain uplift, but its equivalent is prominent not far west in Arizona.

EAST-CENTRAL VALENCIA COUNTY.

GENERAL RELATIONS.

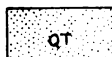
The region extending from Cebolleta Mesa to the Sierra Lucero is in general a broad basin, whose west side rises to the faulted zone on the western margin of the Rio Grande basin. The principal structural features of the eastern part of this region are shown in the cross sections on Plate XLIX, and the distribution of formations is shown in Plate XLVIII.

Although in general this region is one of widespread monoclines, there are irregularities in dip which may indicate the presence of low domes, anticlines, and structural terraces that might possibly be favorable to the accumulation of oil or gas.



EXPLANATION

SEDIMENTARY ROCKS



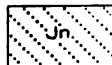
Sand, gravel, and loam



Sandstone and shale of Montana and Colorado ages; Dakota sandstone at base



Morrison shale
(Light-colored massive shale)



Navajo sandstone
(Massive sandstone, in greater part gray; red at base)



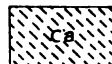
Todilto formation
(Limestone with thick bed of gypsum at top to northeast) on Wingate sandstone
(Mostly pink sandstone)



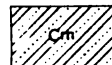
Red shale



Chupadera formation
(Limestone, sandstone, and gypsum)



Abo sandstone
(Red sandstone and sandy shale)



Magdalena group
(Mostly limestone)

IGNEOUS AND METAMORPHIC ROCKS



Lava flows
(Basalt)



Granite, gneiss, etc.

Fault

Strike and dip

Upper Cretaceous

Permian
(Manzano group)

Pennsylvanian

QUATERNARY
AND
TERTIARY (?)

CRETACEOUS (?)

JURASSIC

TRIASSIC

CARBONIFEROUS

PRE-QUATERNARY
AND
CAMBRIAN
TERTIARY

STRATIGRAPHY.

The strata in this region extend from a horizon high in the Mesa-verde to the base of the Magdalena group, which lies on pre-Cambrian granite in the Sierra Ladrones. The following table shows the principal features and thickness of the formations:

Sedimentary formations in the eastern half of Valencia County, N. Mex.

Age.	Group and formation.		Character.	Thickness (feet).
Miocene.	Santa Fe formation.		Silt, clay, sand, and gravel, locally consolidated.	100+
Upper Cretaceous.	Mesaverde formation.		Sandstone, with some shale.	800
	Mancos shale.		Shale with several beds of hard gray to buff sandstone.	1400+
	Dakota sandstone.		Sandstone, gray to buff, hard, partly massive.	80-120
	Morrison formation.		Shale, massive, pale greenish, in part maroon; thins out to south.	160
Cretaceous (?).	Navajo sandstone.		Sandstone, massive; upper member red, lower member gray; thins out to south.	260
	Todilite formation.		Gypsum, white, massive; underlies north-eastern part of county.	0-80
			Limestone, very thin bedded; thins out to south.	0-15
	Wingate sandstone.		Sandstone, massive, mostly pink; thins out to south.	0-160
Triassic.			Red shales and sandstones.	600+
Permian.	Manzano group.	Chupadera formation.	Limestone, gray sandstone, gypsum, and soft red sandstone.	1200
		Abo sandstone.	Sandstone, brown-red, slabby.	800
Pennsylvanian.	Magdalena group.		Limestone, with some sandstone and shale, especially in lower part.	1200+
Mississippian.	Lake Valley limestone.		Limestone, coarse, white; ends in Sierra Ladrones.	0-25

The strata that may possibly contain oil in this succession are the sandstones of the Mesaverde and Mancos formations, which, however, are all cut through by the valleys, and the sandstones in the Chupadera and Magdalena formations, which in part of the area lie at considerable depth. A few deep borings made in this district for water have not found any indications of oil, but apparently they have not

been sunk in places where the structural conditions are favorable. One deep hole is a mile southwest of Suwanee, and another is 11 miles west of that place. In both of these holes there is a small flow of highly mineralized artesian water. The depths are not known but are stated to be somewhat more than 1,000 feet.

LOCAL STRUCTURE.

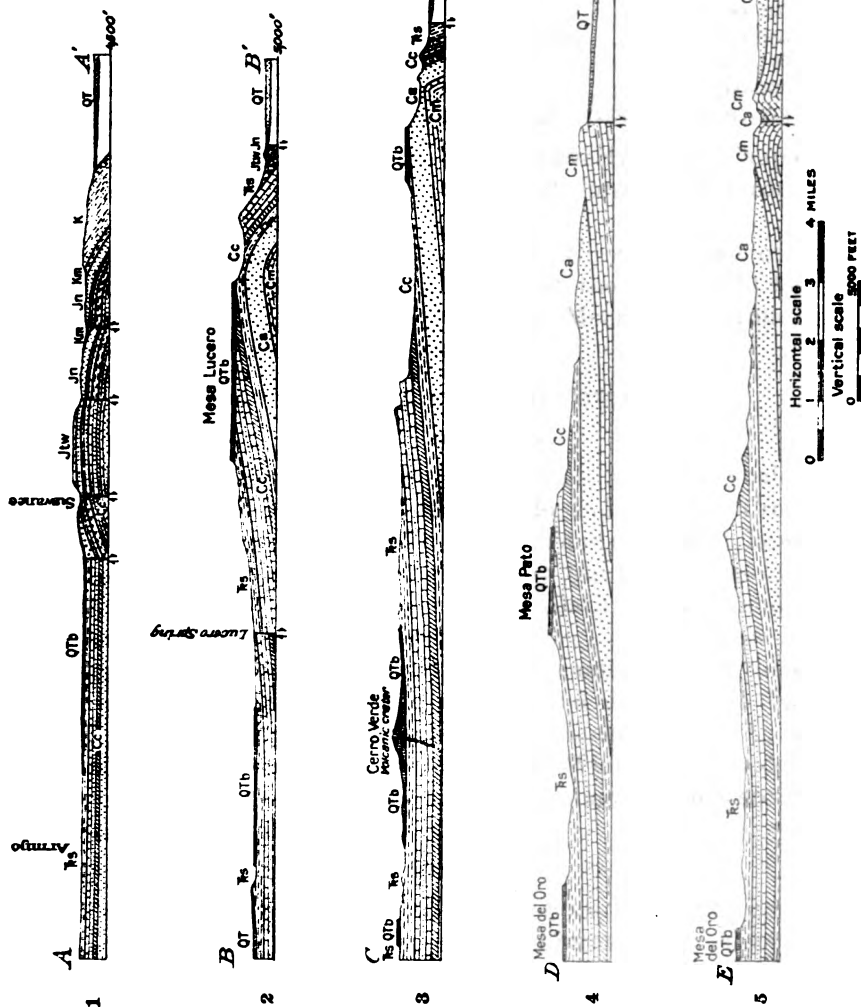
The Lucero or Ladrone anticline rises against the main fault in the vicinity of Mesa Lucero and, as shown in section 2, Plate XLIX, finally presents a complete arch of the Chupadera and the underlying Abo sandstone and Magdalena group. The top of the Magdalena is exposed on Arroyo Carrizo, 7 miles southwest of Rio Puerco station, where the overlying Abo beds dip gently westward on the west side of the axis and steeply eastward on the east side. This form is typical of the anticline with a steep eastern limb on which the higher beds are cut off by the main fault. A short distance west of Garcia siding the anticline is cut off by a fault trending northwest, with the drop on its north side, and the down-faulted block, still presenting anticlinal structure, is split by several north-south faults and cut off on the west by the Mesa Gigante fault, all well exposed north of the Rio San Jose north and east of Suwanee station. The relations in this vicinity are shown in section 1, Plate XLIX. Mesa Redonda is an outlying mass of Cretaceous sandstones preserved by a cap of old lava.

The broad valley of the Arroyo Colorado contains much sand, gravel, and lava, which hide the nearly level Triassic red shales, but local terraces and arches are likely to exist. Westerly dips occur in the high plateaus of the divide between Arroyo Colorado and Arroyo Acoma, carrying the beds into the wide, shallow basin that underlies the Cebolleta Mesa region. This monocline is up-arched by a long, low anticline just north of Acoma, which exposes the Todilto limestone along the arroyo and lower slopes. There are also low domes in the sandstone slopes south of Laguna.

DEEP BORINGS.

A number of deep holes have been bored in this region, but they have not been located where the structure is favorable for oil. They were sunk for water, and some of them obtained satisfactory results. At Rio Puerco station a hole 1,015 feet deep is reported to be entirely in clay and gravel but probably penetrated Cretaceous strata. Very salty water was obtained.

At North Garcia, a siding 7 miles northwest of Rio Puerco, an 855-foot hole obtained only salt water. The record disclosed red and blue clays to 412 feet, then 20 feet of "gravel, below which was red sandstone 100 feet, white sandstone 73 feet, and blue clay 250 feet."



SECTIONS ACROSS SIERRA LUCERO IN VALENCIA AND SOCORRO COUNTIES, N. MEX.

For explanation of symbols see Plate XLVIII.

The hole starts in the valley fill east of the main fault, and it is not possible to recognize the strata penetrated.

Three holes, 235, 225, and 480 feet deep, bored in the upper red beds southwest of Suwanee found flows of salty water.

Three borings, 275, 382, and 853 feet deep, 8 miles south of Laguna were sunk in red beds in the wide flat adjoining the west fork of Arroyo Colorado. Artesian flows of salt water were found. The record of one of these wells is as follows:

Record of boring in sec. 17, T. 8 N., R. 5 W., 8 miles south of Laguna, Valencia County, N. Mex.

	Feet.
Red clay, sandstone, and gravel.....	0-90
Sandstone, gray; water.....	90-160
Clay, red and brown; with gray clay at 290-410 feet.....	160-560
Sandstone and shale, red; salty water at 610 feet.....	560-700
Sandstone, hard, brown; much salty water.....	700-705
Shale, red, with sandstone layers; salty water at 737-853 feet...	705-853

Apparently all the strata are the red beds overlying the Chupadera formation, and it is unfortunate that the drilling did not continue to the base of that formation.

A 942-foot hole at Armijo, after passing through a bed of lava, penetrated red sandstone and shales and at the bottom 42 feet of gray sandstone, all Triassic beds (Chinle to Moenkopi? formations) that overlie the Chupadera formation.

NORTH-CENTRAL SOCORRO COUNTY.

GENERAL RELATIONS.

There are extensive exposures of limestones, red beds, shale, and coal measures in the valleys of Rio Salado and Alamosa Creek, in north-central Socorro County. To the south and southwest, however, these rocks are unconformably overlain by the thick mass of fragmental and effusive igneous rocks of the Datil, Gallina, and Bear mountains. In general the strata in this region dip at low angles to the south and southwest, toward the mountains, but there are numerous local variations in the amount and direction of dip and several faults. The principal features are shown in Plate L, which is compiled from observations made by D. E. Winchester in a detailed survey of the coal measures.³⁵ Some underground relations are shown in the cross section, figure 42.

STRATIGRAPHY.

The sedimentary rocks in north-central Socorro County comprise strata from the Lake Valley (Mississippian) limestone to coal measures in the Upper Cretaceous, and also gravel, sand, travertine, and other

³⁵ Winchester, D. E., *Geology of Alamosa Creek valley, Socorro County, N. Mex.*: U. S. Geol. Survey Bull. 716, pp. 1-15, 1920.

deposits of late Tertiary and Quaternary age. The following table gives the principal characteristics and thickness:

Sedimentary formations in north-central Socorro County, N. Mex.

Age.	Group and formation.	Characteristics.	Thickness (feet).
Upper Cretaceous.	Mesa Verde formation.	Sandstone, with coal beds.	1,800
	Mancos shale.	Shale, with several sandstone members.	2,000
	Dakota sandstone.	Gray sandstone, hard.	0-60
Triassic.		Red shale.	600
Permian.	Chupadera formation.	Upper beds, limestone, gypsum, and gray sandstone; lower beds, soft red sandstone, with thin gypsum and limestone beds.	1,200
	Abo sandstone.	Brown-red slabby sandstone and red sandy shale.	800
Pennsylvanian.	Magdalena group.	Limestone and shale, with sandstone in lower part.	800-900
Mississippian.	Lake Valley limestone.	Limestone; thins out to north.	0-50
Pre-Cambrian.		Granite.	

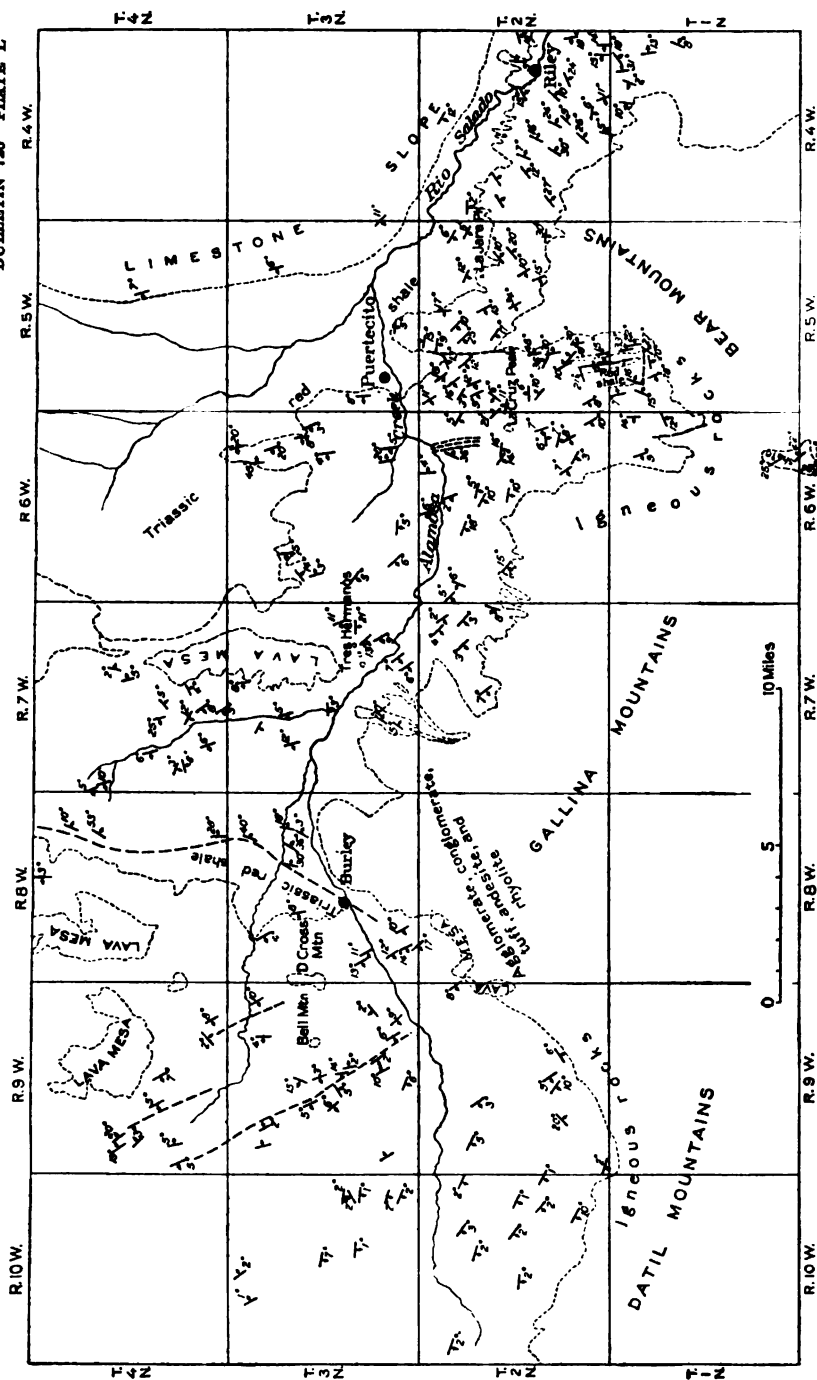
Among the more porous rocks in this succession are the sandstones in the Mancos, Dakota, Chupadera, and Magdalena formations. The Mesaverde sandstones probably do not lie at sufficient depth and in much of the area the massive sandstone of the Mancos formation also is too near the surface to be suitable as a reservoir, even where the structure may be favorable.

LOCAL STRUCTURE.

The best-defined anticline in the area extends northward from Burley post office. It brings up the Triassic red shale in an outcrop area about 10 miles long, cut off on the east side by a fault with a displacement of several hundred feet. A smaller uplift, with a similar fault on the east side, occurs $5\frac{1}{2}$ miles west of Burley. A small faulted dome brings up red beds again 3 miles southeast of La Cruz Peak. Some fainter structural disturbances appear in the center of T. 4 N., R. 7 W., and 3 miles southwest of Puertocito, extending southeastward nearly to La Cruz, possibly connecting with the dome above mentioned 3 miles southeast of that peak.

BORINGS.

The only boring reported in the region is a test for oil or gas made at a point about 3 miles east of La Jara Peak. It had reached a depth of about 300 feet in 1916.



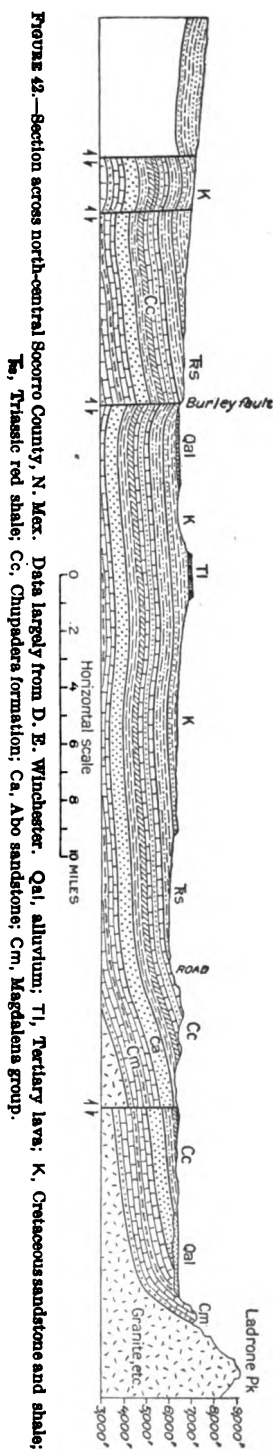
MAP SHOWING STRUCTURE OF VALLEYS OF RIO SALADO AND ALAMOSA CREEK, N. MEX.

Mainly from data furnished by Dean E. Winchester.

WEST-CENTRAL VOLCANIC AREA.

The central and western parts of Socorro County, the northwestern part of Sierra County, and the northern part of Grant County are occupied by a large area of Tertiary volcanic rocks which appear to mask the underlying formations completely. These volcanic rocks consist of widespread sheets of agglomerate and tuff, interbedded with extensive flows of latite, andesite, rhyolite, and basalt, lying mostly level but locally tilted and faulted to a greater or less extent. Very few data have been obtained as to the succession or structure of these rocks, and they present no possibility whatever for oil or gas. It has been stated that underlying Cretaceous sandstone appears near Reserve, but this statement has not been verified. To judge from the complex faulting and flexing of the strata in the Silver City-Hanover region, it appears likely that the sedimentary rocks, which no doubt underlie the igneous rocks, may present many complexities of structure, especially to the south. At the north end of the area, however, in the vicinity of Salt Lake and in the valley of Alamosa Creek, in the northern part of Socorro County, the Cretaceous rocks pass under the northern edge of the volcanic series in a widely extended, gently southward-dipping monocline. How far south this structure or these relations extend can only be surmised. If borings are sunk in the great area of igneous rocks and specimens of the borings are preserved it may be possible to ascertain some of the structural and stratigraphic conditions, but until this is done no oil predictions will be justified in the area indicated.

In 1920 a boring was in progress in sec. 17, T. 3 N., R. 14 W., about 16 miles north-east of Quemado.



PLAINS OF SAN AGUSTIN.

The Plains of San Agustin occupy an area of about 300 square miles in the central part of Socorro County. Their average width is about 12 miles. On nearly all sides are ridges and mountains of igneous rocks. The general altitude of the remarkably level valley floor is about 6,850 feet.

Very little has been ascertained as to the structural relations in this area, but the rocks of the adjoining ridges lie nearly horizontal, and although there are many faults the plains are not bounded by them and apparently consist of much younger beds, which comprise several hundred feet of loam, sand, and gravel derived from the adjoining mountains and partly filling an old valley between them. Several wells have been sunk in this filling, apparently without reaching bedrock.

The following data, supplied by Dean E. Winchester, are all that are available:

Data on wells in Plains of San Agustin, Socorro County, N. Mex.

Location.	Depth (feet).	Results.
Northeastern part of T. 1 S., R. 8 W.	300	Plenty of good water.
Southwest corner of T. 2 S., R. 7 W.	171	
South-central part of T. 3 S., R. 7 W.	292	
Northeastern part of T. 3 S., R. 6 W.	335	
Center of T. 3 S., R. 9 W.	280	Plenty of good water; 100 feet of gravel, then red clay and pebbles.
Center of T. 4 S., R. 11 W.	125	Plenty of good water.

In 1920 a boring for oil was in progress in sec. 8, T. 2 S., R. 8 W., about 10 miles east of Datil.

FAIRVIEW TO LAKE VALLEY.

Limestones and sandstones of Carboniferous to Cambrian age crop out at intervals along the east slope of the Black Mountains and Mimbres Range, and the pre-Cambrian granite appears near Hillsboro Peak. The rock outcrops are separated by an extensive overlap of talus and other younger formations, and there is much faulting, so that the structural relations are difficult to ascertain.

The section in figure 43, by C. H. Gordon,²⁸ shows the complex relations in the Hillsboro region. East of Fairview I found an eastward-dipping succession of limestone of the Magdalena group, red Abo sandstone, and limestones and sandstones of the Chupadera formation, and on Palomas Creek, 10 miles southwest of Chuchillo, the Abo sandstone reappears. At Hermosa there are very extensive exposures of the Magdalena group underlain by the Lake Valley limestone and Percha shale. The greater part of the high mountains west of these

²⁸ U. S. Geol. Survey Prof. Paper 68, fig. 16, p. 224, 1910.

places consists of the Tertiary igneous succession described on page 186, and the igneous rocks also appear in a zone of ridges extending through the eastern parts of Tps. 10 to 17 S., R. 7 W. At Lake Valley there appears in the center of this ridge zone an eastward-dipping succession of rocks of Ordovician to Mississippian (Lake Valley) age. Owing to the complexities of structure and interruptions of outcrops by igneous rocks and superficial deposits it was not possible to ascertain the structural conditions. Locally there may be anticlines and domes in which oil or gas could accumulate if they were present.

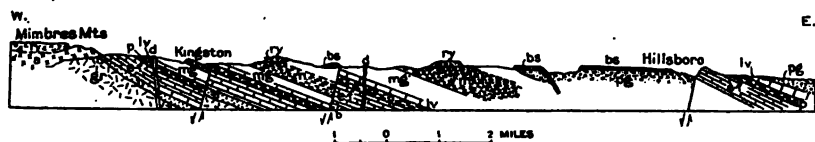


FIGURE 43.—Section from the Mimbres Mountains eastward through Kingston and Hillsboro, N. Mex. (After Gordon.) gr, Granite; b, Bliss sandstone; e-f, Mimbres limestone [El Paso, Montoya, and Fusselman limestones]; p, Percha shale; ls, Lake Valley limestone; mg, Magdalena group; m, Manzano group; pg, Palomas gravel; bs, basalt sheet; a, andesite; ry, rhyolite; d, dike.

SOUTHWESTERN COUNTIES.

GENERAL RELATIONS.

Luna, Grant, and Hidalgo counties consist of detached ridges made up largely of volcanic rocks, with wide desert valleys containing thick deposits of sand and gravel. The structure of many of the ridges has been determined,³⁷ but the conditions under the wide, flat-floored deserts between them are not known, and few borings have been deep enough to reach the bedrock. The sedimentary rocks of the region range from Cambrian sandstone (Bliss) to late Cretaceous and Tertiary deposits and have an aggregate thickness of several thousand feet. The underlying pre-Cambrian granite and schist appear in a few places, and large bodies of Tertiary volcanic rocks, both effusive and fragmental, overlap the other rocks with a great variety of relations. The sedimentary rocks exposed in the ridges are tilted and flexed and in most places greatly faulted, and undoubtedly similar flexing and faulting prevails under the deserts and under the wide covers of igneous rocks, most of which were accumulated since the principal flexing and faulting. The igneous masses, are, however, also tilted, flexed, and faulted to a considerable extent. In many parts of the region there are rocks that might possibly contain petroleum, and at a few places the structural conditions appear favorable, but no authentic evidence of the existence of oil or gas has been obtained. In many areas the large amount of fault-

³⁷ Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916. Darton, N. H., *Idem*, Deming folio (No. 207), 1917; *Geology and underground water of Luna County, N. Mex.*: U. S. Geol. Survey Bull. 618, 1916.

ing and the former heat of igneous rocks may be unfavorable. Deep borings for oil near Lordsburg and Columbus appear to have been located without any consideration of geologic conditions. It is reported that the hole at Columbus had reached a depth of 1,900 feet early in 1919. Many of the ridges showing sedimentary rocks are tilted blocks rising out of the desert on one side and showing steep faces on the other, most of them traversed by numerous faults, an unfavorable structural condition. A brief description of some of these mountains may be of interest, especially as the rocks which they represent undoubtedly underlie some of the adjacent valleys. Detailed descriptions of the ridges in Luna County will be found in the two reports above cited.

COOKS RANGE.

Cooks Range, a southern extension of the Mimbres Range, is a conspicuous feature in the northern part of Luna County. It consists of an uplifted block of limestone and sandstone, from Cretaceous to Cambrian in age, traversed by a large stock of porphyry constituting Cooks Peak. The basement of old granite appears in places. Along the east side and at the north and south ends of the range are thick bodies of the Tertiary igneous series, consisting of agglomerate, tuff, and lava flows of various kinds. The fault along the east side of the range has a drop of about 1,000 feet on the east.

FLORIDA MOUNTAINS.

The Florida Mountains are a high and exceedingly rugged ridge a few miles southeast of Deming. The northern half of the ridge and the outlying Little Florida Mountains consist of agglomerate and other igneous rocks, and the southern half is pre-Cambrian granite overlain in the small central area by sandstones and limestones of Cambrian to Permian age. The rocks are tilted in the same direction and traversed by great faults. The principal structural features are shown in figure 44, introduced here because it shows also the relations in parts of the adjoining plains.

FLORIDA PLAINS.

The structural relations under the wide desert plains on each side of the Florida Mountains are not known. A few widely scattered rock outcrops are of very diverse character. The Snake Hills (see section, fig. 45), 10 miles southwest of Deming, consist of limestone (El Paso and Montoya) dipping gently westward, possibly on the west slope of an anticline, the location of whose crest, however, is not indicated. On the crest there would probably be only a small thickness of the El Paso limestone and Bliss sandstone lying on granite. It may be that the strata on the northwest slope of the Florida Mountains are on the east slope of the arch, and under this

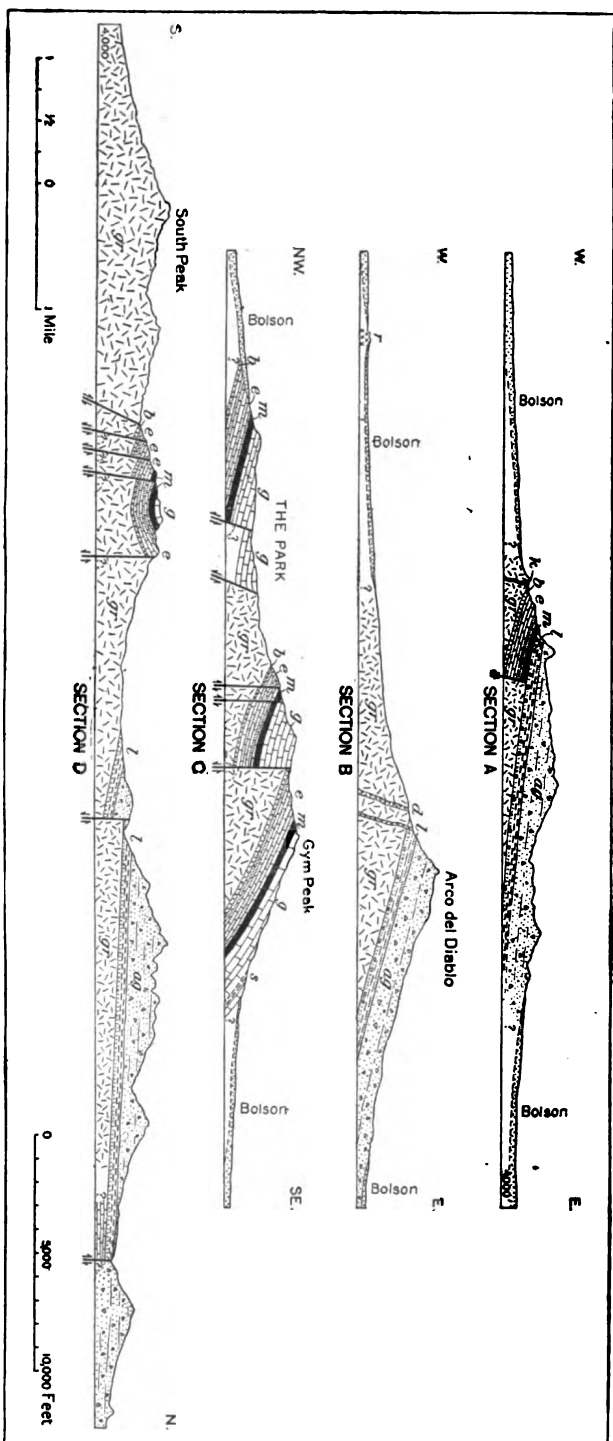


FIGURE 44.—Sections across the Florida Mountains, Luna County, N. Mex. A, From Capital Dome; B, from Arco del Diablo; C, through The Park and Gym Peak; D, from south to north along the higher part of the range. *h*, Black sandstone; *e*, El Paso limestone; *m*, Montoya and Fusselman limestones; *r*, felsitic rhyolite in White Hills; *d*, rhyolite porphyry dikes; *l*, Lobo formation; *s*, Gym limestone; *g*, black shale member; *k*, keratophyre; *gr*, granite; *ag*, agglomerate.

condition the crest would be granite under the deep valley south of Deming. Several deep holes sunk for water in this general region were entirely in valley fill. One in sec. 20, T. 24 S., R. 8 W., 6 miles southeast of Deming, was 1,665 feet deep; another in Deming was 980 feet deep; and a third $3\frac{1}{2}$ miles east of Deming was 710 feet deep. A boring for oil in T. 23 S., R. 10 W., 6 miles northwest of Deming, had reached a depth of 1,565 feet in 1920. Clay and sand were found to a depth of 430 feet, then limestone, shale, sandstone, and "gravel" to 1,430 feet, white limestone to 1,515 feet, and red shale to the bottom.

Another well 22 miles southeast of Deming, in the SW. $\frac{1}{4}$ sec. 8, T. 25 S., R. 6 W., is being drilled for oil. The strata reported are

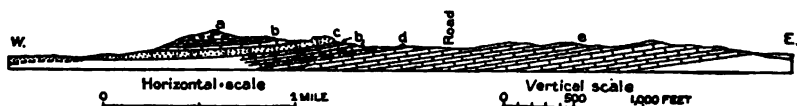


FIGURE 45.—Section through the Snake Hills, southwest of Deming, Luna County, N. Mex. a-d, Montoya limestone (a, limestone with chert in large bodies; b, cherty members; c, massive dark-gray sandy limestone; d, massive dark limestone at base); e, El Paso limestone.

alternations of gravel, clay, and sand. The sand contains a large amount of water. Notable artesian flows were found at 580, 594, 650, and 670 to 700 feet.

GOODSIGHT MOUNTAINS.

The Goodsight Mountains, which extend southward from Sunday Cone, in Sierra County, to a point about 10 miles northwest of Cambray, consist entirely of volcanic rocks. The principal feature is a thick cap of basalt on agglomerate, both tilted to the east at a low angle.

TRES HERMANAS MOUNTAINS AND ADJOINING PLAINS.

The prominent peaks of the Tres Hermanas Mountains, in the south-central part of Luna County, consist of porphyry intruded in the Gym limestone. This limestone crops out here and there on the slopes of the ridges, in most places dipping away under the adjoining plains. How far it extends under the plains and what are its underground relations can not even be suggested. Wells in the country near Columbus indicate that these plains are underlain by a thick body of valley fill. The deepest hole reported is one 975 feet deep on the Shay ranch, in sec. 6 or 7, T. 28 S., R. 7 W. Another well in sec. 26, T. 27 S., R. 7 W., was 500 feet deep. One in the NE. $\frac{1}{4}$ sec. 26, T. 28 S., R. 7 W., is 510 feet deep; one in the SW. $\frac{1}{4}$ sec. 4, T. 29 S., R. 9 W., is 500 feet deep; and one in sec. 9, T. 29 S., R. 7 W., is 500 feet deep. A deep boring for oil in the NW. $\frac{1}{4}$ sec. 16, T. 29 S., R. 7 W., was unsuccessful. The occurrence of oil in this region is improbable, and there is no evidence whatever as to the underground structure.

CEDAR GROVE MOUNTAINS AND CARRIZALILLO HILLS.

The high ridge that extends across the southwest corner of Luna County and is crossed by the El Paso & Southwestern Railroad just west of Hermanas, including the Cedar Grove Mountains and the Carrizalillo Hills, consists entirely of volcanic rocks in thick sheets. The sheets dip to the northeast at low angles and undoubtedly underlie the plains for some distance toward the Tres Hermanas Mountains and Iola.

KLONDIKE HILLS.

The small outlying ridge in T. 26 S., R. 13 W., known as the Klondike Hills, consists mainly of Ordovician limestones, which are domed as shown in figure 46. This dome, with its granite outcrop



FIGURE 46.—Section through the Klondike Hills, Luna County, N. Mex. gr, Granite and gneiss; b, Bliss sandstone; e, El Paso limestone; m, Montoya limestone, with sandstone (s) at its base; r, rhyolite.

in the center, is not favorable for oil or gas. Possibly other domes less uplifted and eroded exist under the wide plains of Luna and Grant counties, but they are buried by gravel and sand.

VICTORIO MOUNTAINS.

The isolated group of hills known as the Victorio Mountains lie just south of Gage, 20 miles west of Deming. The main ridge consists of a sheet of andesite dipping 20°–25° NNE. In the hills just

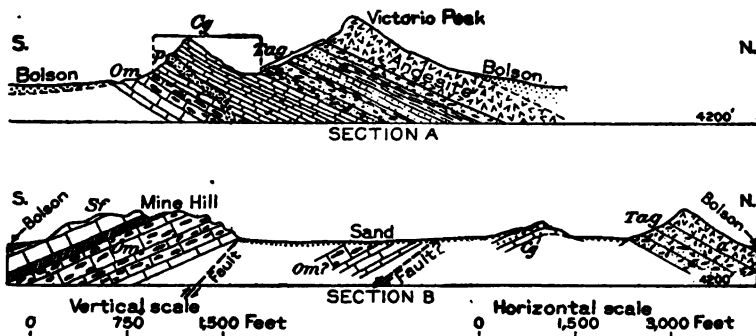


FIGURE 47.—Sections across the Victorio Mountains, south of Gage, Luna County, N. Mex. a, Andesite; Tag, agglomerate, shale, and sandstone; Cg, Gym limestone; Sf, Fusselman limestone; Om, Montoya limestone; Oe, El Paso limestone; p, porphyry.

south of it are Ordovician, Silurian, and Carboniferous limestones, cut by igneous rocks and dipping in various directions. Faulting also complicates the relations. The two sections in figure 47 show that there is a dome in the center of the area, but the depth to the granite is very small, and there has been much metamorphism, mineralization, and faulting, so that there appears to be no chance for petroleum.

RIDGES IN NORTHWEST CORNER OF LUNA COUNTY.

Cow Cone, Grandmother Mountain, Red Mountain, Gray Butte, and other hills and ridges in the northwest corner of Luna County all consist of rhyolite of various kinds, with small showings of basalt and agglomerate. No evidence is revealed as to the nature or structure of the sedimentary rocks, and moderately deep holes to the south and near Spaulding and Red Mountain show that the valley fill is more than 300 feet thick in places.

BIG HATCHET MOUNTAINS.

The Big Hatchet Mountains consist of Ordovician to Carboniferous formations flexed in various directions and lying on granite, which is exposed in several places. At the north end of the range there is a fine dome, in which, however, the underlying granite is lifted so high that there is no prospect for an oil reservoir. The relations of this area are shown by the cross section in figure 48. This section is

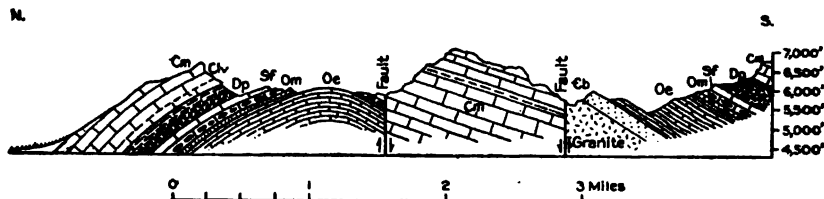


FIGURE 48.—Sketch section across the north end of the Big Hatchet Mountains, Hidalgo County, N. Mex. Cb, Bliss sandstone; Oe, El Paso limestone; Om, Montoya limestone; Sf, Fusselman limestone; Dp, Percha shale; Clv, probable Lake Valley limestone; Cm, Magdalena group.

important in showing for the first time a succession of the strata constituting the Paleozoic rocks of the region. To what extent these rocks underlie the surrounding basins and the thick accumulations of volcanic materials in the adjoining ridges is not known. At the southwest end of the range are thick beds of limestone, sandstone, and shale of Comanche age, which are also conspicuous in some of the adjoining ridges, notably in the Sierra Rica and Apache Hills, in and adjoining the extreme southwest corner of Luna County. These strata are extensively cut and overlain by a variety of igneous rocks.

LITTLE HATCHET MOUNTAINS.

The Little Hatchet Mountains, 6 to 12 miles west of Hachita, present a considerable variety of rocks and structural conditions. Only a portion of the range was examined. At Old Hachita there are exposures of light-colored limestones of Comanche age forming an anticline or dome, and these beds, with associated shales and sandstones, are extensively exposed in some of the ridges to the southwest, notably in the Sylvanite mining district. They are cut by igneous rocks and overlain by tuffs, agglomerates, and lava flows of various kinds. The general dip is to the southwest, and the

structural relations are complex. In places the strata are considerably altered by the igneous rocks.

ANIMAS MOUNTAIN AND SAN LUIS RANGE.

The wide, high ridge known as Animas Mountain, extending from a point near the El Paso & Southwestern Railroad in the southwestern part of Hidalgo County 40 miles southward to the Mexican line, so far as examined consists mainly of Tertiary igneous rocks, with some limestones and shales of Comanche age on the central eastern slope. These sedimentary rocks appear in an irregular dome faulted on several sides just south of Gillespie Mountain, and although they may be wholly included in igneous rocks they may possibly be underlain by 1,800 feet or more of Paleozoic limestone. Some portions of the adjacent San Luis Range are limestone, and limestones are reported at the north end of Animas Mountain.

PELONCILLO MOUNTAINS.

The high range of the Peloncillo Mountains, extending southward to the Mexican boundary from the gap through which the El Paso & Southwestern Railroad passes west of Pratt, apparently consists entirely of Tertiary igneous rocks, and nothing is known of the underlying beds. The southern continuation of the range past Pratt and Steins Pass shows a variety of rocks, mostly volcanic but including Paleozoic limestones and supposed pre-Cambrian granite, all very greatly disturbed and faulted. Granite Gap evidently marks an east-west fault with granite on the north side and lower Paleozoic limestones on the south. Gilbert²² reported that limestones and sandstones of probable Paleozoic age, in which Carboniferous fossils were noted, occur in Gabilan Peak. "The strata dip at a high angle toward both flanks of the range, and upon their upturned edges rests the granite which constitutes the peak." On account of this relation and much metamorphism of the strata the granite was regarded as igneous.

The only hole reported in this region is one on the plain 10 miles west of Lordsburg. It attained a depth of 700 feet—the first 340 feet in clay and gravel and the lower part in blue clay, gravel, and "cement" of unknown age.

PYRAMID MOUNTAINS.

The irregular high ridge area extending northward from Little Pyramid Peak to Lordsburg shows only Tertiary igneous rocks. Possibly there is an underlying core of sedimentary beds, but the nature of these beds and their relations and structure under the adjoining valleys can not be determined.

²² Gilbert, G. K., U. S. Geog. and Geol. Surveys W., 100th Mer. Rept., vol. 3, p. 514, 1875.

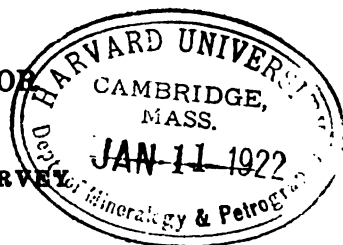
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ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 726—F



GEOLOGIC STRUCTURE AND
OIL AND GAS PROSPECTS OF A PART OF
JEFFERSON COUNTY, OKLAHOMA

BY

HEATH M. ROBINSON

Contributions to economic geology, 1921, Part II
(Pages 277-302)

Published December 20, 1921



WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

CONTENTS.

	Page.
Introduction.....	277
Area and location.....	277
Accessibility.....	277
Water available for drilling.....	277
Previous geologic work in this and adjacent areas.....	277
Field work.....	278
Acknowledgments.....	278
Stratigraphy.....	278
Exposed rocks.....	278
Age.....	278
"Red Beds".....	279
Wichita formation.....	279
Definition.....	279
Correlation.....	279
Local details.....	280
Trinity sand (?).....	283
Tertiary (?) residual deposits.....	284
Sand dunes and alluvium of Quaternary age.....	285
Unexposed rocks.....	285
Character as shown by surface studies.....	285
Character as shown by a study of well logs.....	286
Structural features.....	297
Regional structure.....	297
Local structure.....	298
General conditions.....	298
Seay anticline.....	299
Grogan anticline.....	299
Red Creek anticline.....	299
Other folds.....	299
Suggestions to prospectors.....	300
General rating of the area.....	300
Recommendations.....	301
Conclusions.....	302

ILLUSTRATIONS.

	Page.
PLATE LI. Index map of Oklahoma.....	278
LII. Map showing the geologic structure in a part of Jefferson County, Okla.....	284
FIGURE 49. Diagram showing principal sandstone and conglomerate beds that were found serviceable in mapping the structure of a part of Jefferson County, Okla.....	281

GEOLOGIC STRUCTURE AND OIL AND GAS PROSPECTS OF A PART OF JEFFERSON COUNTY, OKLAHOMA.

By HEATH M. ROBINSON.

INTRODUCTION.

Area and location.—The area described in this report embraces about 175 square miles in the southern part of Jefferson County, Okla. Its precise location in the State is shown on Plate LI. As shown on Plate LII the mapped area is bounded on the north by the northern boundary of T. 6 S., on the east by the eastern boundary of R. 5 W., on the west by the western boundary of R. 7 W., and on the south by Red River.

Accessibility.—The Chicago, Rock Island & Pacific Railway crosses the western part of the area. The towns of Ryan and Terral are on this railroad and are distributing points for all parts of the area. All the roads shown on Plate LII have been traveled with an automobile, and as the country is characterized for the most part by gentle slopes, the roads have very few steep grades and heavy loads may be transported to practically any locality without great difficulty. Most of the country is open prairie in which it is possible to do rapid and efficient geologic mapping with the plane table and telescopic alidade.

Water available for drilling.—The principal streams that contain water throughout the year within and adjacent to this area are Red River, Beaver Creek, Fleetwood Creek, Red Creek, and Bird Baker Creek. Water for drilling may also be obtained from ponds, "tanks" (artificial reservoirs in which surface water is collected), or shallow water wells.

Previous geologic work in this and adjacent areas.—The area treated in this report is just southeast of a part of the area in Jefferson County mapped and described by C. H. Wegemann.¹ A bulletin of the Oklahoma Geological Survey gives a description of Jefferson County, with particular reference to its oil and gas prospects, and states the conclusion² that "Taking everything into consideration, Jefferson County is in favorable territory, and it is probable that in future drilling new fields may be discovered."

¹ Anticlinal structure in parts of Cotton and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 602, 1915.

² Shannon, C. W., and others, Petroleum and natural gas in Oklahoma, Part II: Oklahoma Geol. Survey Bull. 19, pt. 2, p. 241, 1917.

Fritz Aurin ³ discusses the general structure of the area covered by the "Red Beds." J. A. Udden and D. McN. Phillips ⁴ treat in a general way of the country in Texas southwest of Jefferson County, Okla. C. H. Gordon, ⁵ in a report on the geology and underground waters of the Wichita region of north-central Texas, includes a geologic map that covers the area just south of Jefferson County, Okla., and a very good bibliography on the geology of north-central Texas. Hager ⁶ cites a number of tests for oil and gas near Red River, which have penetrated Ordovician limestone and in some places granite. According to the map with his paper this uplift of the older rocks includes southern Jefferson County, Okla.

Field work.—The field work on which this report is based was done by the writer, who was assisted during a part of December, 1917, by H. R. Mann, and in June and July, 1918, by Lewis Mosburg.

A 15 by 15 inch plane table and telescopic alidade were used in mapping the structure over that part of the area in which traceable beds of sandstone and conglomerate were found. The land lines form the basis for the areal control of the map (Pl. LII), and the elevations on the rock outcrops were obtained either by direct level readings or by the use of vertical angles. The elevations were checked among themselves by means of a system of triangulation and also with the Government bench marks that have been established in the area, which are shown on the Montague and Addington topographic maps published by the United States Geological Survey.

Acknowledgments.—Thanks are due and are extended to the field assistants for their willingness and efficiency in their work and to the oil companies and individuals who generously supplied copies of the logs of tests and other information. The writer is also indebted to his colleagues of the United States Geological Survey for helpful suggestions and criticisms.

STRATIGRAPHY.

EXPOSED ROCKS.

AGE.

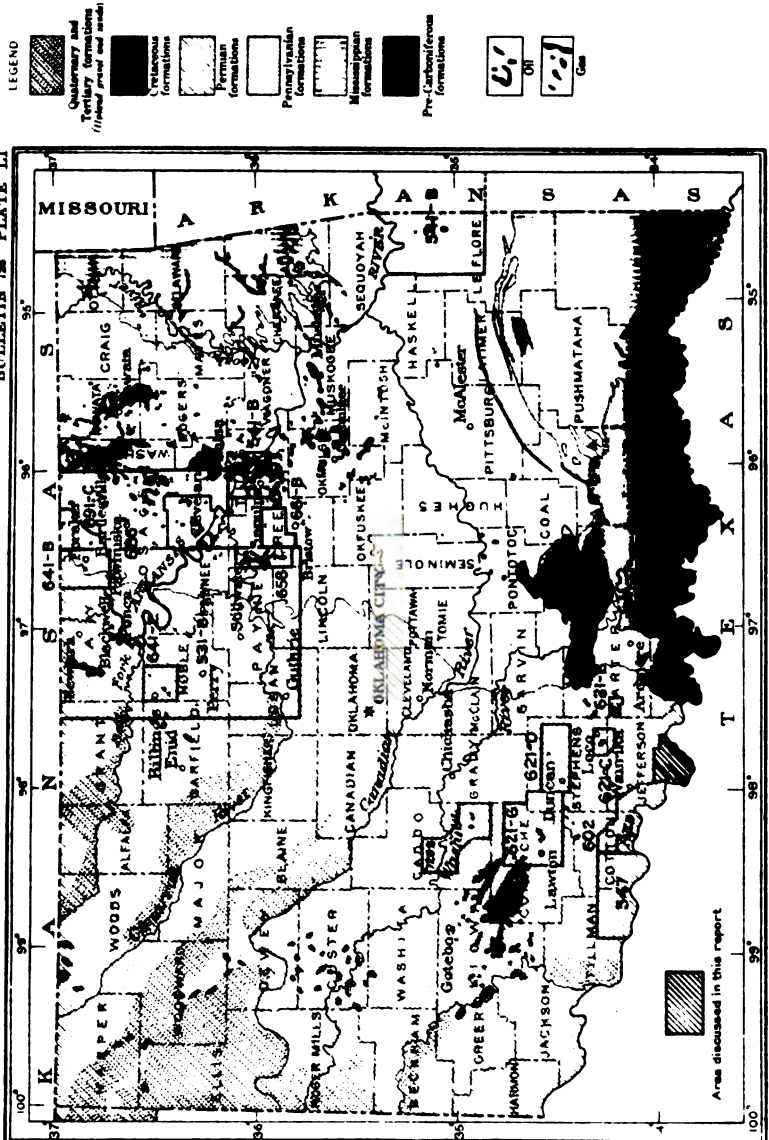
The oldest rocks exposed in the area are probably of Permian age, though possibly the top of the Pennsylvanian is present. The great bulk of the exposed rocks are Permian, a part of the area is covered by unconsolidated sediments which are tentatively classed as Lower Cretaceous, and the youngest rocks are deposits of alluvium and sand dunes of Quaternary age. The hard rocks of the section may be

³ Geology of the Red Beds of Oklahoma: Oklahoma Geol. Survey Bull. 30, 1917.

⁴ A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties, Tex.: Texas Univ. Bull. 246, 1912.

⁵ U. S. Geol. Survey Water-Supply Paper 317, 1913.

⁶ Red River uplift has another angle: Oil and Gas Jour., Oct. 17, 1919.



GEOLOGIC MAP OF OKLAHOMA SHOWING OIL AND GAS FIELDS

Heavy numbers refer to numbered bulletins in which other oil fields in Oklahoma are described

conveniently described under the heading "Red Beds," for their predominant color is red and it is a term that is in very common use.

"RED BEDS."

The "Red Beds" of north-central Texas were originally divided by the Texas Geological Survey into three formations, in descending order the Double Mountain, Clear Fork, and Wichita. Of these only the Wichita formation is present in the area described in this report.

WICHITA FORMATION.

DEFINITION.

The Wichita formation was named from its typical exposures in Wichita County and along Wichita River, Tex. As originally defined⁷ it overlies the coal measures (Cisco formation), underlies the Clear Fork formation, and consists of fossiliferous sandstones, sandy shales, clays, and a peculiar conglomerate.

The sandstones and sandy shales are red, gray, and variegated, often containing large oval concretions, ranging in size from one-quarter of an inch to several feet in diameter. The sandstones are often shaly in structure but in places are massive. They are frequently ripple marked and in places have a cross-bedded structure. The concretions are very hard and retain the peculiar structure of the sandstone in which they occur. The clays are red and bluish. In the red clays are nodular masses of clay, iron, and lime, which often take the form of geodes, filled with tabular lime-spar in the center. The bluish clay is copper bearing in many places. The conglomerate is composed of rounded pieces of clay or clay ironstone cemented together by iron.

CORRELATION.

In the area described in the present report the "Red Beds" above and including bed A, described beyond (see fig. 49), are referred without question to the Wichita formation. The beds below bed A may possibly be, at least in part, of Pennsylvanian age and referable to the Cisco formation. The predominant color of the upper part of the Cisco formation in this region is red, and it is difficult to separate the Cisco and Wichita formations on the basis of lithology alone. The boundary between these two formations is indicated on the map by Gordon⁸ as intersecting Red River a mile or so west of the Chicago, Rock Island & Pacific Railway bridge about a mile south of Terral, Okla. The boundary line is drawn with dotted lines, indicating that there is doubt about its exact location. The country on the Oklahoma side of Red River near the railway bridge is covered by alluvium, sand dunes, and other unconsolidated sediments, and therefore it is impossible to determine the exact location of the boundary between the Wichita and Cisco formations in the area discussed in this

⁷ Dumble, E. T., and Cummins, W. F., Texas Geol. Survey First Ann. Rept., pp. lxvii-lxix, 185-189, 1890.

⁸ Gordon, C. H., op. cit., pl. 1.

report. Inasmuch as the Permian is unconformable with the underlying Pennsylvanian rocks in the vicinity of the Arbuckle Mountains, and the basal beds of the Permian in that region are more or less conglomeratic, it would seem logical to assume, in the absence of other more conclusive evidence, that the conglomeratic beds of the area under discussion should be classed as Permian rather than as Pennsylvanian. Therefore the boundary between the Wichita and the underlying Cisco formation is tentatively assumed to be at some horizon below the conglomerate described as bed A.

LOCAL DETAILS.

The hard ledges of sandstone and conglomerate in the "Red Beds" are the most important beds exposed in this area from the viewpoint of the oil geologist who wishes to map the structure of the region, and for that reason these hard ledges are described somewhat in detail below.

The outcrops of the principal sandstone and conglomerate beds are shown on Plate LII by solid lines where they are continuously exposed and by dashed lines where it is believed the beds would crop out if the surface material covering them were removed. The stratigraphic position of these beds and their areal distribution are shown in figure 49. The principal beds shown in this figure have been labeled by letters, and the corresponding beds are shown on Plate LII, similarly lettered. As pictured in figure 49, the sandstone and conglomerate beds are very lenticular. This characteristic is purposely emphasized in the figure by making the vertical scale greater than the horizontal scale, in order to give a more graphic picture of the beds that must be used to map the detailed structure of the area. On an average these rock lenses are less than 2 miles long, and they attain a maximum thickness of about 50 feet. Their upper surfaces are not even, but the thickness of the individual beds being taken into consideration, it is likely that contours drawn on the tops of these beds will not be in error more than 10 feet. As shown in figure 49 and on Plate LII some of these individual beds may be traced for 2 miles, but it is difficult to correlate with certainty one lens with another where it is impossible to follow their outcrops on the ground. In spite of the difficulties, however, it is possible to show very closely the structure of the surface beds where the sandstone and conglomerate beds are well exposed.

A number of these sandstone lenses were found to contain conglomeratic phases, and the lowest lens, bed A (see fig. 49), is made up almost wholly of conglomerate. The pebbles in bed A are composed for the most part of chert, and they have an average diameter of about three-fourths of an inch, although pebbles as thick as $1\frac{1}{2}$ inches were noted. The pebbles are interbedded with

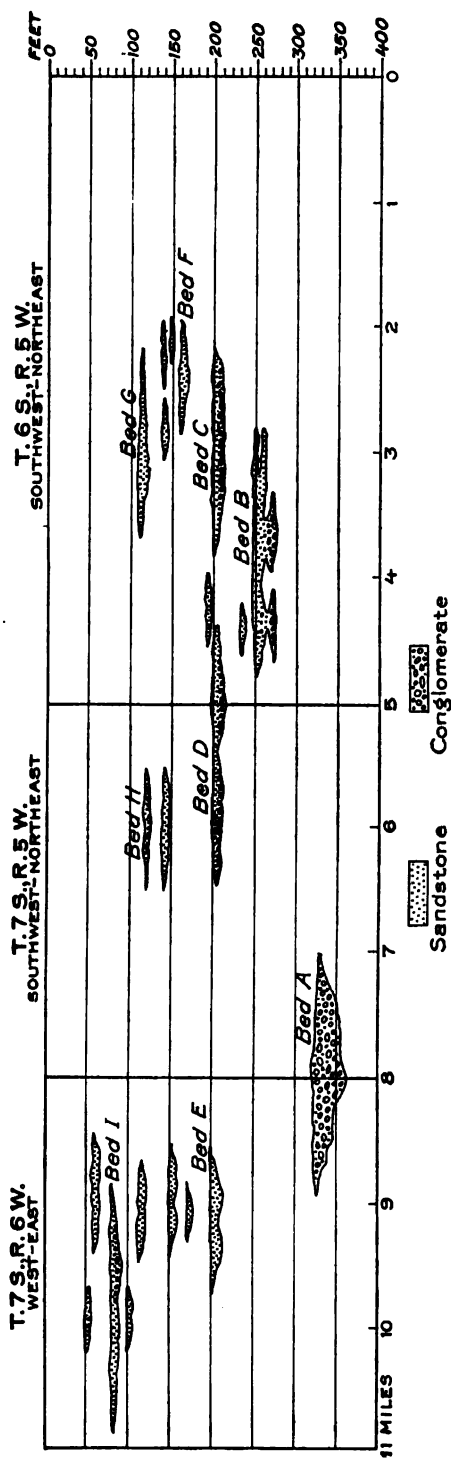


FIGURE 49.—Diagram showing principal sandstone and conglomerate beds that were found serviceable in mapping the structure of a part of Jefferson County, Okla., arranged according to their stratigraphic and areal positions. The material associated with these beds consists mainly of red clay interbedded with variegated clays, shale, and thin friable sandstones. Vertical scale exaggerated. Beds are lettered to agree with text and with Plate LII.

small stringers of sandstone, and the matrix of the conglomerate is made up largely of coarse sand and fine-grained pebbles. The conglomerate is cross-bedded, ripple marks are common on its upper surface, and it attains a maximum thickness of about 50 feet.

Bed B (see fig. 49) is probably stratigraphically higher than bed A, although it was not possible to map the structure between the areas covered by the outcrops of these two beds. This doubtful correlation is also expressed on Plate LII by means of dotted structure contours. Where one bed directly overlies the other the intervals shown in figure 49 are probably very nearly correct, but where one bed does not directly overlie the other the intervals can be considered only approximate. As shown in the figure, the top of bed B is stratigraphically about 70 feet higher than the top of bed A. Bed B is irregular in shape, and its thickness ranges from a few inches to almost 30 feet. The top part of the sandstone in many places weathers into concretionary masses several feet thick, which are dark brown to dark gray on their surfaces that have been exposed to the weather. On fresh surfaces the rock is light gray and contains numerous brown and gray spots. The basal part of the sandstone in some outcrops is conglomeratic.

Bed C and bed D occupy about the same position in the stratigraphic column, and probably they should be correlated. It is not possible, however, to follow the outcrop of bed C where it connects with bed D. The upper part of this sandstone is light gray on both fresh and weathered surfaces. It appears to be made up largely of fairly well rounded quartz grains, and on fresh fractured surfaces it is sprinkled with small black spots, probably due to stains of a manganese mineral. The lower parts of beds C and D are conglomeratic, and the average diameter of the pebbles is about one-fourth of an inch. The pebbles are mostly clear quartz and chert. Both the sandstone and conglomeratic phases are cross-bedded, and the maximum measured thickness of the bed is less than 15 feet.

Bed E is shown in figure 49 to occupy about the same stratigraphic position as beds C, and D, but this correlation is tentative only. Bed E is a nonconglomeratic sandstone which in many places weathers into black concretionary masses and attains a maximum thickness of about 15 feet.

The top of the sandstone called bed F is about 40 feet above the top of bed C and the maximum thickness observed is 10 feet. In some outcrops the sandstone of bed F was found interbedded with small layers of rounded fragments of limestone, but in general the bed is gray on fresh surfaces and differs in no material way from the sandstones described above.

Bed G is stratigraphically about 40 feet above the top of bed F. It is light to dark gray on weathered surfaces, but on fresh surfaces

it contains numerous dark specks, which often weather into small concretions or hard masses that are stained by iron or manganese minerals. It is cross-bedded, and the greatest thickness observed was about 12 feet.

Bed H is a sandstone which in some outcrops is conglomeratic. On fresh surfaces it is light gray and resembles many other sandstones found in this area.

Bed I is a sandstone that is about 10 feet thick in most exposures. It contains stringers of conglomerate with pebbles as much as one-fourth of an inch in diameter and in general resembles the sandstones described above. Stratigraphically its top is shown in figure 49 to be about 40 feet above bed H, although this interval must be considered approximate only.

From the above descriptions it will be seen that on the whole there is little to differentiate one sandstone or conglomerate from another, so that the only reliable means of correlation is by tracing out exposures on the ground.

The sediments between the sandstones and conglomerates consist for the most part of red clay, which is interbedded with variegated clays and shales and thin friable sandstones. An outcrop of carbonaceous shale about 6 inches thick was found in the SW. $\frac{1}{4}$ sec. 18, T. 7 S., R. 5 W., about 8 feet above bed A. This is mentioned because it is the only carbonaceous bed found exposed in the area. Exposures of red clay and massive sandstone were found in an interval of about 100 feet below the top of bed A in the river bluffs in sec. 19, T. 7 S., R. 5 W. The thickness, color, and other characteristics of the individual clay and shale beds are so diverse that it is believed to be impossible to use these beds for purposes of correlation except in a broad and general way.

TRINITY SAND (?).

An area embracing about 8 square miles northeast of the town of Terral is covered with loose sand, which is tentatively correlated with the Trinity sand, of Lower Cretaceous age. The area covered by this body of sand is shown on Plate LII. The sand is apparently associated with scattered pebbles, but no well-cemented beds of conglomerate were observed, and it is possible that the pebbles may be of later age than the loose sand. The contact between the sand and the underlying older beds dips toward the southeast, at the rate of about 25 feet to the mile. The contact is over 950 feet above sea level in secs. 22 and 23, T. 7 S., R. 7 W., and a little over 850 feet above sea level in sec. 6, T. 8 S., R. 6 W. Although this sand body is fairly close to the river, it does not seem to be connected with the sand dunes just north of the river in this locality, and the inclined contact would argue against this being a terrace deposit. The

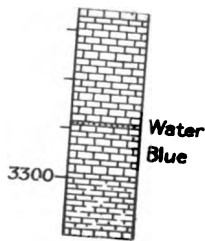
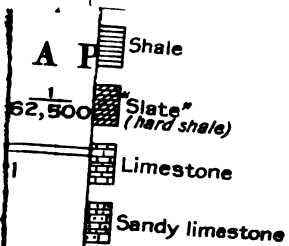
topography of the area covered by this sand body is not particularly flat, as would be expected if the deposit were due to the deposition of sand on an old terrace of Red River. In a few localities the wind has scooped out small basins in the sand, which are represented by depression contours on the topographic map of the Montague quadrangle. These basins are similar to the forms found in any very sandy area where the sand is loose enough to be shifted by the wind into dunes.

At present it is impossible to determine the age of this sand body definitely, because no fossils were found in it, and no conclusive lithologic criteria were discovered by which it might be correlated with formations of known geologic age. In lithology, however, it resembles the Trinity sand, which is exposed about 20 miles to the east. The Trinity sand in the southwest corner of Carter County, Okla., consists of a fairly clean quartz sand that makes traveling difficult for an automobile or wagon, a characteristic which is equally well shown by the sand northeast of Terral. The elevation of the base of the Trinity sand in T. 5 S., R. 3 W., about 20 miles northeast of the sand body in the area mapped, is about 900 feet above sea level. The contact between the sand and the underlying beds about 2 miles northeast of the town of Terral (see Pl. LII), southwest of the locality just mentioned, is also about 900 feet above sea level. As the normal strike of the base of the Cretaceous in this general region is southwest, this outlier of sand is in the place where one would expect to find it with a normal dip of the Cretaceous rocks. Furthermore, the rate of dip of the base of the Cretaceous in the vicinity of T. 5 S., R. 3 W., is similar to the rate of dip of the base of the deposit of sand outlined on Plate LII. As both the lithologic and structural evidence point to the correlation of this sand deposit with the lower part of the Trinity sand, of Lower Cretaceous age, it is tentatively assumed that this correlation is correct.

TERTIARY (?) RESIDUAL DEPOSITS.

In many localities in the area treated in this report the surface of the ground is covered with loose pebbles, from 1 to 6 inches in diameter, most of which are made up of vein quartz, quartzite, chert, and fine-grained conglomerate. They were not found consolidated into a conglomerate at any locality and hence must be considered residual deposits, representing either a conglomerate that once covered the surface or old stream gravels that have never been consolidated into a conglomerate. They might easily have been derived from a conglomerate equivalent in age and similar in character to the Grandfield conglomerate, described by Munn.⁹ These pebbles

⁹ Munn, M. J., Reconnaissance of the Grandfield district, Okla.; U. S. Geol. Survey Bull. 547, pp. 529-530, 1914.



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are not thick enough to obscure the hard ledges in the "Red Beds," and consequently they are of little importance in determining the oil and gas prospects of this area.

SAND DUNES AND ALLUVIUM OF QUATERNARY AGE.

A belt of country 1 to 2 miles wide that is covered by alluvium and sand dunes borders a large part of the north bank of Red River in this area. The alluvium is made up chiefly of sandy red clay and silt, and the sand dunes are composed of sand that has been carried from the dry part of the bed of the river and deposited on the land near by. The tops of some of these sand dunes are more than 50 feet above the level of the surrounding country. Both the sand dunes and the alluvium serve as a blanket that effectively conceals the underlying "Red Beds," and they are important in pointing out to the oil geologist those areas where it is not possible to find outcrops of the older rocks, which are necessary in order to map the structure accurately. The soil over much of the area that has not been dissected by streams contains more or less of the finer wind-blown material, which is more pronounced near Red River and less pronounced and finer in texture northward from the river.

UNEXPOSED ROCKS.

Information concerning the rocks beneath the surface of the area under consideration may be obtained in two ways—by a study of these older beds in other localities where they are exposed, and by a study of the well logs in this and near-by areas.

CHARACTER AS SHOWN BY SURFACE STUDIES.

The Pennsylvanian rocks of north-central Texas are briefly described by C. H. Gordon ¹⁰ as follows, in descending order:

Section of Pennsylvanian formations in Wichita region, Tex.

Cisco formation (clay, shale, conglomerate, and sandstone, with some limestone and coal).....	Feet. 800
Canyon formation (alternating beds of limestone and clay, with some sandstone and conglomerate).....	800
Strawn formation (alternating beds of sandstone and clay, with some conglomerate and shale; the lower 1,000 feet consists of blue and black clay locally containing beds of limestone, sandstone, or sandy shale and a coal seam at the top).....	1,900
	3,500

The Wichita formation, classed as Permian, overlies the Cisco formation (Pennsylvanian) and is exposed over the greater part if not the whole of the area treated in this report. It constitutes at least

¹⁰ Gordon, C. H., op. cit., p. 14.

the upper and probably the major part of the "Red Beds" penetrated in the test holes which have been drilled in this area. According to Gordon ¹¹ the upper part of the Cisco formation is red in the vicinity of Red River, and the boundary between the Cisco and the Wichita formations can be located only approximately where these formations crop out farther south, in Archer and Montague counties, Tex.

From surface studies only it could be forecast that a test well in southern Jefferson County would probably pass through several hundred feet of "Red Beds" belonging to the Wichita formation and possibly at the base to the Cisco formation, then into several hundred feet of blue and gray shales and sandstones belonging to the Cisco formation, and then into the underlying Canyon and Strawn formations.

CHARACTER AS SHOWN BY A STUDY OF WELL LOGS.

Although it is possible to get many useful data concerning the subsurface formations by a study of these formations at their outcrop, more detailed information can be obtained by a study of the logs of test holes that have been drilled in or near the area under study, if enough holes have been drilled and if good records have been kept. In the area treated in this report nine test holes have been drilled for oil and gas. They are indicated on Plate LII and for convenience in description are numbered.

The available information concerning these holes is given below. The well records are given just as they were reported by the drillers, and it is probable that careful examination of the drill cuttings would give somewhat different logs. However, the records as given can be used for general purposes of correlation.

Test hole No. 1, near the center of sec. 28, T. 6 S., R. 5 W., is reported to have been drilled with cable tools to a depth of 2,091 feet. It was a dry hole at this depth. The following is a copy of the driller's log of this test:

1. Driller's log of B. B. Jones well, on Oscar Seay farm.

	Feet.		Feet.
Surface.....	0-20	Red rock.....	273-300
Sandrock.....	20-25	Blue shale.....	300-315
Red rock.....	25-45	Sand; water.....	315-330
Sand; water.....	45-65	Red rock.....	330-345
Light shale.....	65-90	Blue shale.....	345-350
Red rock.....	90-205	White slate.....	350-365
Sand; water.....	205-237	Blue shale.....	365-380
Red rock.....	237-260	Black slate.....	380-390
Blue shale.....	260-273	Sand; water.....	390-400

¹¹ Gordon, C. H., op. cit., p. 19.

1. Driller's log of B. B. Jones well, on Oscar Seay farm—Continued.

	Feet.		Feet.
Red rock.....	400-425	Red rock.....	1, 130-1, 140
Sand; water.....	425-455	Blue shale.....	1, 140-1, 150
White shale.....	455-466	Lime shell.....	1, 150-1, 155
Red rock.....	466-475	Blue shale.....	1, 155-1, 195
White clay.....	475-485	Red rock.....	1, 195-1, 220
Sand, brown; water.....	485-515	Pink shale.....	1, 220-1, 240
Red rock.....	515-565	Sandy lime.....	1, 240-1, 243
Light slate.....	565-575	Blue shale.....	1, 243-1, 245
Red rock.....	575-680	Sand; water.....	1, 245-1, 270
Blue shale.....	680-700	Blue shale.....	1, 270-1, 420
Sand.....	700-710	Sand, water.....	1, 420-1, 435
Hard rock.....	710-713	Blue shale.....	1, 435-1, 500
Sand.....	713-725	White mud.....	1, 500-1, 540
Blue slate.....	725-745	Shell.....	1, 540-1, 542
Sand; water.....	745-765	Brown shale.....	1, 542-1, 570
Lime.....	765-770	Sand; water.....	1, 570-1, 580
Blue slate.....	770-775	White shale.....	1, 580-1, 610
Sand.....	775-795	Sand; water.....	1, 610-1, 635
Blue slate.....	795-818	Blue shale.....	1, 635-1, 795
Sand; water.....	818-835	Shell.....	1, 795-1, 797
Flint.....	835-890	Sandy shale.....	1, 797-1, 845
Light shale.....	890-893	Blue shale.....	1, 845-1, 850
Sand, hard.....	893-899	Blue shale.....	1, 850-1, 900
Brown shale.....	899-901	Brown shale.....	1, 900-1, 930
Lime and sand.....	901-914	Blue shale.....	1, 930-1, 950
Blue shale.....	914-1, 014	White shale.....	1, 950-1, 973
Lime shell.....	1, 014-1, 019	Hard lime.....	1, 973-2, 010
Blue shale.....	1, 019-1, 095	Blue shale.....	2, 010-2, 020
Red rock.....	1, 095-1, 105	Hard lime.....	2, 020-2, 091
Light slate.....	1, 105-1, 130		

Test hole No. 2, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 35, T. 6 S., R. 5 W., is reported to have been drilled with cable tools to a depth of 3,358 feet and abandoned. The following is a copy of the log of this test:

2. Drillers' log of Oscar Seay well No. 1.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	Feet.	Feet.		Feet.	Feet.
Soil.....	10	10	Sand.....	60	1, 345
Clay, yellow.....	40	50	Shale.....	20	1, 385
Shale, blue.....	50	100	Sand.....	18	1, 403
Sand.....	32	132	Shale.....	35	1, 438
Rock, red; fresh water.....	70	202	Sand.....	23	1, 463
Shale.....	63	265	Shale.....	15	1, 478
Lime.....	20	285	Lime.....	12	1, 490
Shale.....	10	295	Shale, black.....	5	1, 495
Sand.....	25	320	Shale, blue.....	20	1, 515
Rock, red.....	20	340	Sandy shale.....	60	1, 575
Shale.....	23	363	Slate, black.....	23	1, 598
Rock, red.....	30	393	Sandy shale.....	77	1, 675
Rock, red.....	87	480	Sand.....	5	1, 680
Shale.....	172	652	Shale.....	100	1, 780
Rock, red.....	325	977	Sand.....	23	1, 805
Shale.....	227	1, 204	Shale.....	15	1, 820
Lime.....	24	1, 228	Sand.....	13	1, 835
Shale.....	77	1, 305	Lime, black.....	5	1, 840

2. Driller's log of Oscar Seay well No. 1—Continued.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
Sand.....	10	1,850	Shale.....	2	2,402
Shale.....	10	1,860	Sand.....	18	2,420
Sand.....	5	1,865	Sandy lime.....	20	2,440
Sandy lime.....	25	1,890	Lime.....	18	2,458
Sand.....	35	1,925	Sand.....	5	2,463
Sandy shale.....	10	1,935	Lime.....	22	2,485
Sand.....	60	1,995	Sand.....	87	2,572
Shale.....	5	2,000	Shale.....	10	2,582
Shale.....	17	2,017	Sand.....	5	2,587
Sand.....	5	2,022	Sandy shale.....	18	2,605
Shale.....	4	2,026	Sandy lime.....	22	2,627
Sand.....	25	2,051	Shale.....	3	2,630
Shale.....	11	2,062	Broken lime.....	7	2,637
Sand.....	70	2,132	Sand.....	33	2,670
Lime.....	18	2,150	Sand, white; dry.....	39	2,709
Sand.....	15	2,165	Sandy lime.....	356	3,065
Lime.....	75	2,240	Sand; dry.....	20	3,085
Hard sand.....	10	2,250	Lime.....	12	3,097
Shale.....	9	2,259	Sand; showing of gas.....	8	3,105
Lime.....	2	2,261	Lime.....	137	3,242
Shale.....	67	2,328	Sand; water.....	5	3,247
Sand.....	22	2,350	Lime, blue.....	53	3,300
Sandy shale.....	10	2,360	Broken lime and shale.....	58	3,358
Sand.....	40	2,400			

* Last shale horizon. From this point down the drill cuttings show continuously a sand formation; most of the cuttings run 80 per cent sand and 18 to 20 per cent lime; sand grains are very small, cemented by CaCO_3 .

Test hole No. 3, in the SW. $\frac{1}{4}$ sec. 3, T. 7 S., R. 5 W., was drilled to a reported depth of about 2,350 feet and abandoned. A copy of the log of this hole to a depth of 2,207 feet follows:

3. Driller's log of Seay well No. 2, Empire Gas & Fuel Co.

	Feet.		Feet.
Soil.....	0-6	Blue shale.....	443-466
Sand.....	6-38	Red rock.....	466-474
Blue shale.....	38-70	Blue shale.....	474-510
Water sand.....	70-99	Water sand.....	510-515
Red rock.....	99-105	Red rock.....	515-520
Blue shale.....	105-150	Blue shale.....	520-540
Gritty shale.....	150-155	Gray shale.....	540-564
Sand.....	155-175	Blue shale.....	564-590
Shale.....	175-178	Sand.....	590-620
Sand.....	178-200	Lime.....	620-620
Shale.....	200-230	Water sand.....	630-668
Sand.....	230-250	Blue shale.....	668-710
No record.....	295-300	Hard sandy lime.....	710-716
Blue shale.....	250-262	Blue shale.....	716-806
Sand.....	262-295	Shell.....	806-807
No record.....	295-300	Blue shale.....	807-828
Red rock.....	300-323	Shell.....	828-833
Blue shale.....	323-326	Blue shale.....	830-975
Shale.....	326-330	Water sand.....	975-1,004
Red rock.....	330-392	Lime.....	1,004-1,032
Blue shale.....	392-396	Blue shale.....	1,032-1,099
Red mud.....	396-422	Sand.....	1,099-1,121
Blue shale.....	422-430	Shale.....	1,121-1,128
Red mud.....	430-443	Blue shale.....	1,126-1,180

3. Driller's log of Seay well No. 2, Empire Gas & Fuel Co.—Continued.

	Feet.		Feet.
Sand.....	1, 180-1, 183	Sandy lime, hard.....	1, 744-1, 750
Sand.....	1, 183-1, 208	Lime.....	1, 750-1, 810
Blue shale.....	1, 208-1, 234	Break, shale.....	1, 810-1, 812
Hard shell.....	1, 234-1, 247	Lime, dark.....	1, 812-1, 823
Blue shale.....	1, 247-1, 280	Blue shale.....	1, 823-1, 852
Dark shale.....	1, 280-1, 335	Lime, pink.....	1, 852-1, 895
Shale.....	1, 335-1, 345	Blue shale.....	1, 895-1, 900
Sand.....	1, 345-1, 370	Sandy shale.....	1, 900-1, 920
Dark shale.....	1, 370-1, 450	Shale, blue.....	1, 920-1, 930
Lime shell.....	1, 450-1, 455	Shale, sandy.....	1, 930-1, 955
Shale.....	1, 455-1, 482	Shale, blue.....	1, 955-1, 965
Sand; little water.....	1, 482-1, 487	Shale, sandy.....	1, 965-1, 985
Shale.....	1, 487-1, 490	Sand, water.....	1, 985-2, 005
Blue shale.....	1, 490-1, 535	Shale.....	2, 005-2, 010
Sandy shale.....	1, 535-1, 545	Lime shell.....	2, 010-2, 012
Shale, light.....	1, 545-1, 581	Sandy shale.....	2, 012-2, 017
Lime shell.....	1, 581-1, 582	Blue shale.....	2, 017-2, 030
Shale.....	1, 582-1, 602	Water sand, white.....	2, 030-2, 040
Sandy shale.....	1, 602-1, 614	Sandy shale.....	2, 040-2, 060
Water sand.....	1, 614-1, 642	Water sand.....	2, 060-2, 075
Shale.....	1, 642-1, 662	Water sand.....	2, 075-2, 100
Sand, hard.....	1, 662-1, 680	Blue shale.....	2, 100-2, 105
Shale.....	1, 680-1, 690	Sandy shale.....	2, 105-2, 120
Sand, hard.....	1, 690-1, 697	Sandy shale.....	2, 120-2, 125
Sandy shale.....	1, 697-1, 714	Blue shale.....	2, 125-2, 130
Shale.....	1, 714-1, 718	Lime, white, hard; stopped	
Water sand, soft.....	1, 718-1, 723	in this limestone at about	
Sand.....	1, 723-1, 740	2,350 feet.....	2,140-2,350±
Shale.....	1, 740-1, 744		

Test hole No. 4, in the SE. $\frac{1}{4}$ sec. 14, T. 7 S., R. 6 W., was reported as being drilled in October, 1920.

Test hole No. 5, in the SW. $\frac{1}{4}$ sec. 3, T. 7 S., R. 6 W., is reported to have been drilled with a rotary to a depth of 1,592 feet and abandoned. Shows of oil and gas were reported at 665 and 1,568 feet. A copy of the log of this hole follows:

5. Driller's log of test hole in the SW. $\frac{1}{4}$ sec. 3, T. 7 S., R. 6 W.

	Feet.		Feet.
Sand, hard.....	0-81	Shale.....	203-314
Sand, hard.....	81-91	Sand, hard.....	314-322
Shale, red, sandy.....	91-126	Shale.....	322-337
Sand and shale.....	126-133	Sand.....	337-366
Sand.....	133-157	Sand, hard.....	366-391
Shale.....	157-163	Gumbo.....	391-407
Sand.....	163-165	Sand, hard.....	407-438
Red gumbo.....	165-171	Sand, hard.....	438-490
Shale, mixed.....	171-189	Blue shale.....	490-518
Sand.....	189-192	Gumbo.....	518-536
Shale, mixed.....	192-198	Sand.....	536-540
Shale.....	198-203	Gumbo.....	540-566

5. Driller's log of test hole in the SW. $\frac{1}{4}$ sec. 3, T. 7 S., R. 6 W.—Continued.

	Feet.		Feet.
Shale.....	566-590	Sand, hard.....	1, 178-1, 184
Sand, hard.....	590-604	Blue gumbo.....	1, 184-1, 222
Sand, hard.....	604-616	Sand, hard.....	1, 222-1, 224
Blue gumbo.....	616-664	Blue gumbo.....	1, 224-1, 248
Oil sand (light showing)....	664-680	Shale.....	1, 248-1, 252
Shale.....	680-710	Blue gumbo.....	1, 252-1, 272
Sand, hard.....	710-724	Blue shale.....	1, 272-1, 287
Blue gumbo.....	724-810	Sand, hard.....	1, 287-1, 293
Shale.....	810-866	Blue shale.....	1, 293-1, 313
Sand, hard.....	866-884	Sandy shale.....	1, 313-1, 324
Sandy shale.....	884-900	Sand, hard.....	1, 324-1, 326
Blue gumbo.....	900-937	Shale.....	1, 326-1, 358
Gumbo.....	937-941	Sand, hard.....	1, 358-1, 376
Shale.....	941-951	Black shale.....	1, 376-1, 388
Sand, hard.....	951-963	Blue shale.....	1, 388-1, 449
Blue gumbo.....	963-975	Sand, hard.....	1, 449-1, 471
Shale.....	975-986	Limerock.....	1, 471-1, 499
Sand, hard.....	986-1, 017	Blue gumbo.....	1, 499-1, 517
Blue gumbo.....	1, 017-1, 038	Sand, hard.....	1, 517-1, 541
Oil sand.....	1, 038-1, 046	Blue gumbo.....	1, 541-1, 551
Gumbo, blue.....	1, 046-1, 052	Black shale.....	1, 551-1, 561
Sand, hard.....	1, 052-1, 163	Limerock.....	1, 561-1, 567
Blue gumbo.....	1, 163-1, 178	Gas and oil sand.....	1, 567-1, 592

Test hole No. 6, in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 10, T. 7 S., R. 6 W., is reported to have been drilled with cable tools to a depth of 2,000 feet and abandoned. A show of gas was reported at 1,525 feet. A copy of the log follows:

6. Driller's log of Marion Oil & Gas Co.'s well No. 1, on Samuel Wray farm.

	Feet.		Feet.
Cellar.....	0-18	Sand; water.....	740-760
Sandrock.....	18-21	Red rock.....	760-820
Red rock.....	21-130	Sand; water.....	820-840
Sand; water.....	130-140	Red rock.....	840-900
Red rock.....	140-170	Blue shale.....	900-1, 000
Sand; water.....	170-180	Sand, dry.....	1, 000-1, 010
Red rock.....	180-210	Blue shale.....	1, 010-1, 030
Sand; water.....	210-225	Sand; water.....	1, 030-1, 050
Red rock.....	225-300	Brown shale.....	1, 050-1, 065
Sand; water.....	300-340	Sand, dry.....	1, 065-1, 075
Red rock.....	340-380	Blue shale.....	1, 075-1, 100
Blue shale.....	380-410	Sand, dry.....	1, 100-1, 110
Red rock.....	410-430	Blue shale.....	1, 110-1, 120
Sand, dry.....	430-445	Sand; water.....	1, 120-1, 140
Blue shale.....	445-505	Sandy lime.....	1, 140-1, 160
Sand; water.....	505-525	Blue shale.....	1, 160-1, 165
Red rock.....	525-600	Sand, hard; gas; water.....	1, 165-1, 250
Blue shale.....	600-640	Blue shale.....	1, 250-1, 375
Sand; water.....	640-680	Sand; water.....	1, 375-1, 395
Red rock.....	680-740	Blue shale.....	1, 395-1, 495

6. Driller's log of Marion Oil & Gas Co.'s well No. 1, on Samuel Wray farm—Contd.

	Feet.		Feet.
Sand, dry.....	1,495-1,505	Sand; water.....	1,850-1,925
Blue shale.....	1,505-1,535	Blue shale.....	1,925-1,930
Sand; gas (8 to 10 million cu- bic feet).....	1,535-1,560	No record.....	1,930-1,950
Blue shale.....	1,560-1,615	Blue shale.....	1,950-1,965
Sand; water.....	1,615-1,640	Sand; water.....	1,965-1,990
Blue shale.....	1,640-1,850	Blue shale.....	1,990-2,000

Gas sand found from 1,535 to 1,560 feet carried water in the bottom, which was drilled into and was unable to get water shut off and could not be saved for gas well.

Test hole No. 7, in the SE. $\frac{1}{4}$ sec. 5, T. 8 S., R. 6 W., is reported to have been drilled to a depth of 1,450 feet.

Test hole No. 8, in the southeast corner of the SW. $\frac{1}{4}$ sec. 3, T. 8 S., R. 7 W., is reported to have been drilled to a depth of 1,040 feet and abandoned.

Test hole No. 9, in the NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 9, T. 6 S., R. 7 W., is reported to have been drilled to a depth of 1,735 feet and abandoned. A copy of the log of this test follows:

9. Driller's log of Ryan City Oil Co.'s well.

	Thick- ness.	Depth.		Thick- ness.	Depth.
	Feet.	Feet.		Feet.	Feet.
Gumbo, red.....	40	40	Sand, brown.....	18	910
Rock, red.....	15	55	Gumbo, blue.....	73	983
Gumbo, red.....	32	87	Rock, brown.....	47	1,030
Gumbo, blue.....	43	130	Gumbo, blue, brown.....	81	1,111
Rock, red, sandy.....	6	136	Rock, lime mixture.....	6	1,117
Gumbo, red.....	53	189	Gumbo, blue.....	62	1,179
Sand, white, dry.....	7	196	Rock, blue and red.....	20	1,199
Gumbo, blue.....	62	258	Sand, white; water.....	8	1,207
Rock, red, sandy.....	73	331	Gumbo, blue.....	48	1,255
Gumbo, blue.....	84	415	Gumbo, reddish.....	73	1,328
Pack sand, reddish.....	37	452	Rock sand, red.....	27	1,355
Rock, brown sand.....	45	500	Gumbo, brown.....	35	1,390
Rock, sandy, red.....	17	517	Gumbo, blue.....	83	1,473
Gumbo, reddish.....	68	585	Rock, limish.....	7	1,480
Rock, brown.....	23	608	Sand, white; gas showing.....	13	1,493
Shale, blue.....	90	698	Gumbo, blue.....	96	1,589
Sand, white; gas showing.....	9	707	Sandrock, reddish.....	34	1,623
Gumbo, blue.....	57	764	Gumbo, blue.....	93	1,716
Pack sand, reddish.....	43	807	Rock, brown, lime; casing set.....	4	1,720
Gumbo, red.....	72	879	Sand, brown-white; gas showing.....	15	1,735
Rock, sandy, red.....	13	892			

A number of deep test holes that have been drilled in the territory surrounding the area mapped give valuable information concerning the structure and the character of the rocks below the surface.

A test hole 5 miles north of Myra, Cooke County, Tex., and about 35 miles southeast of the Oscar Seay test hole in sec. 35, T. 6 S., R. 5 E., Okla., is reported¹² to have found black shale from 1,590 to 1,640 feet and lime from 1,640 to 2,675 feet. Hager states that the hole was drilled to a depth of about 3,000 feet and that lime was

¹² Hager, Lee, Oil and Gas Jour., Oct. 17, 1919, p. 61.

found between 2,675 and 3,000 feet. He also says that "Dr. Udden has identified samples from this well as of Ordovician age."

In the same paper is given a condensed log of the test hole known as the Producers Oil Co.'s Byers No. 36, which is in the Petrolia oil and gas field, in northern Clay County, Tex. This field is about 18 miles west of the western boundary of the area shown on Plate LII. Hager reports that Ordovician fossils were found in samples from the drill cuttings of this test hole.

Byers No. 41, drilled by the same company near Petrolia, Tex., is a very deep hole. Although it is outside of the area described in this report, it is important in the matter of correlating subsurface beds between the Petrolia field and the beds found in the test holes drilled in southern Jefferson County, and consequently the detailed log is published and discussed below.

Driller's log of Texas Co.'s Byers No. 41 well, in the southeast corner of block 19, Byers subdivision, W. R. Gaston survey A-191, near Petrolia, Clay County, Tex.

	Feet.		Feet.
Clay.....	0-68	Gray wet sand.....	1,385-1,390
Wet sand.....	68-78	Hard white lime, dry.....	1,390-1,393
Clay, red.....	78-175	Hard blue shale, dry.....	1,393-1,710
Dry sand, gray.....	175-190	Soft red shale.....	1,710-1,735
Red shale.....	190-280	Blue shale, dry, soft.....	1,735-1,753
Brown shale.....	280-300	Hard dry gas sand.....	1,753-1,758
Red shale.....	300-565	Blue shale.....	1,758-1,780
Brown shale.....	565-635	Hard blue shale and slate...	1,780-1,820
Gray wet sand.....	635-660	Blue slate.....	1,820-1,845
Blue hard shale.....	660-690	Sand, wet; hole full.....	1,845-1,975
Hard gray wet sand.....	690-703	Blue hard sandy shale.....	1,975-1,990
Soft blue shale.....	703-715	Wet sand; hole full.....	1,990-2,010
Red and blue shale.....	715-723	Hard blue lime and sand...	2,010-2,040
Soft red shale.....	723-795	Hard sand; big water sand...	2,040-2,080
Brown shale.....	795-820	Gray sandy lime, wet.....	2,080-2,090
Soft red shale.....	820-900	Hard wet sand.....	2,090-2,105
Hard brown shale.....	900-945	Gray sandy lime.....	2,105-2,125
Hard brown sandy shale...	945-965	Wet sand.....	2,125-2,170
Red shale.....	965-970	Hard dry sand.....	2,170-2,175
Hard gray wet sand.....	970-980	Hard white dry lime.....	2,175-2,195
Soft blue shale.....	980-1,016	Wet sand.....	2,195-2,205
Hard blue sandy shale.....	1,016-1,036	Gray lime.....	2,205-2,250
Soft blue shale.....	1,036-1,110	Wet sand.....	2,250-2,275
Hard gray wet sand.....	1,110-1,128	Blue shale.....	2,275-2,281
Soft blue shale.....	1,128-1,140	Wet sand, hard.....	2,281-2,300
Hard blue shale.....	1,140-1,160	Dry gray lime.....	2,300-2,330
Soft blue shale.....	1,160-1,195	Wet sand.....	2,330-2,340
Hard gray sand.....	1,195-1,215	Hard blue shale.....	2,340-2,344
Hard blue shale.....	1,215-1,230	Wet sand, hard.....	2,344-2,355
Soft red dry shale.....	1,230-1,255	Hard gray lime.....	2,355-2,370
Soft blue dry shale.....	1,255-1,350	Hard blue shale.....	2,370-2,390
Hard gray dry sand.....	1,350-1,360	Hard sandy lime, dry.....	2,390-2,420
Blue shale.....	1,360-1,385	Hard blue shale.....	2,420-2,423

Driller's log of Texas Co.'s Byers No. 41 well, in the southeast corner of block 19, Byers subdivision, W. R. Gatton survey A-191, near Petrolka, Clay County, Tex.—Contd.

	Feet.		Feet.
Hard sandy lime, dry.....	2, 423-2, 460	Hard blue lime.....	3, 395-3, 400
Hard sandy lime.....	2, 460-2, 480	Blue shale.....	3, 400-3, 420
Gray lime.....	2, 480-2, 495	Gray lime.....	3, 420-3, 435
Blue lime.....	2, 495-2, 510	Blue slate.....	3, 435-3, 480
Gray lime.....	2, 510-2, 535	Gray lime.....	3, 480-3, 510
Blue shale.....	2, 535-2, 538	Blue shale.....	3, 510-3, 555
Gray lime.....	2, 538-2, 600	Gray lime.....	3, 555-3, 560
Yellow lime.....	2, 600-2, 625	Blue shale.....	3, 560-3, 585
Gray lime, hard, sandy.....	2, 625-2, 670	Blue lime.....	3, 585-3, 630
Gray lime.....	2, 670-2, 685	Blue shale.....	3, 630-3, 710
Gray sandy lime.....	2, 685-2, 745	Blue shale and lime shells..	3, 710-3, 748
White sandy lime.....	2, 745-2, 780	Gray lime.....	3, 748-3, 775
Gray lime.....	2, 780-2, 935	Blue shale.....	3, 775-3, 780
Blue shale.....	2, 935-2, 940	Blue lime.....	3, 780-3, 860
Gray lime.....	2, 940-3, 000	Gray lime.....	3, 860-3, 870
Gray flint lime.....	3, 000-3, 010	Gray sandy lime.....	3, 870-3, 910
Gray lime.....	3, 010-3, 050	White lime.....	3, 910-3, 921
Hard gray sandy lime.....	3, 050-3, 070	Gray lime.....	3, 921-4, 015
Gray lime.....	3, 070-3, 180	Gray sandy lime.....	4, 015-4, 020
Blue shale, soft.....	3, 180-3, 182	Gray lime.....	4, 020-4, 105
Gray lime.....	3, 182-3, 205	Blue shale and lime.....	4, 105-4, 135
Blue shale.....	3, 205-3, 270	Gray lime.....	4, 135-4, 150
Blue lime.....	3, 270-3, 360	Blue shale and lime shell...	4, 150-4, 210
Blue shale.....	3, 360-3, 365	Water sand, hard.....	4, 210-4, 240
Blue lime.....	3, 365-3, 383	Red lime (granite).....	4, 240-4, 289
Blue shale.....	3, 383-3, 395		

The following is a copy of a letter from Mr. P. V. Roundy, of the United States Geological Survey, to the writer, describing samples from this test:

In regard to the Byers No. 41, Clay County, Tex., I wish to state that I have examined under a binocular microscope the well cuttings from 2,700 to 2,905 feet and am unable to find any fossils. Unfortunately the horizons above 2,700 feet are represented in our collections by only one sample, so I am unable to contribute any information concerning that part of the well.

Lithologically the sixteen samples from 2,700 to 2,820 feet consist of white limestone, white chert, fragments of clear quartz crystals, and pyrite. Except for a slight variation in the relative amounts of these constituents, the samples are practically alike. All samples show considerable iron stain.

2,820 to 2,830 feet is not represented in our collections.

The thirteen samples from 2,830 to 2,905 feet consist essentially of the same materials as in the samples above, but there is a greater variation in the relative amounts. In the whole there is much less superficial iron stain. The limestone also varies in color, some pieces having a faint gray to brownish-gray cast.

I consider that the samples from 2,700 to 2,905 are probably from one formation; certainly those from 2,700 to 2,820 are from a single lithologic unit. Without the aid of fossil evidence definite age determinations are of course impossible. I am inclined, on purely lithologic grounds, to consider that these samples all come from rocks of pre-Carboniferous age. If they were from the north-central Texas region, I would consider them as coming from the Ellenburger limestone.

In a letter to the Director of the United States Geological Survey, Mr. Lee Hager states that samples from the Byers No. 41 show the rocks from the bottom of the test hole to be red granite; that at 2,800 feet Ordovician rock was encountered; and that samples obtained above 2,800 feet indicate rocks of Carboniferous age.

It will be noted that Mr. Roundy found that the samples from a depth of 2,700 feet resembled Ordovician rocks, but that Mr. Hager classified the rocks to a depth of 2,800 feet as Carboniferous. It is probable that the contact between the Carboniferous and the Ordovician rocks is an uneven one and does not parallel the lower Carboniferous beds. For this reason a test hole drilled in southern Jefferson County might encounter the top of the Ordovician at a different depth relative to the overlying beds than one drilled in the Petrolia field. It may be concluded that the contact between the Carboniferous and Ordovician rocks in Byers No. 41 is between the depths of 1,919 and 2,800 feet and probably above 2,700 feet.

A test hole drilled on the Halsell lease, 6 miles southeast of Henrietta and about 18 miles southwest of Petrolia, Tex., reached a depth of 3,985 feet without encountering Ordovician rocks.

The log of the test hole drilled on the Oscar Seay farm (No. 2, Pl. LII), in sec. 35, T. 6 S., R. 5 W., shows a great predominance of limestone in the basal 650 feet and a predominance of sandstone and limestone in the 1,000 feet directly overlying the 650 feet of limestone. The section below 1,780 feet is thus made up largely of limestone and sandstone with only a small amount of shale.

From the data at hand it is impossible to establish definitely the exact age of the rocks found in the test holes drilled within the area shown on Plate LII, but it is possible to draw certain conclusions that are of interest to the oil or gas operator who contemplates drilling in this area.

In a zone extending from north-central Cooke County, Tex., across northeastern Montague County, Tex., and southern Jefferson County, Okla. (including the area discussed in this report), and through the Petrolia oil and gas field, in northern Clay County, Tex., thick bodies of limestone, sandy limestone, sandstone, and granite have been encountered at relatively shallow depths in the deeper test holes. The data given above show that thick beds of limestone, sandstone, and sandy limestone were encountered in central Cooke County at 1,640 feet and in Byers No. 41 at Petrolia at 2,010 feet. In southern Jefferson County in the test hole drilled in sec. 35, T. 6 S., R. 5 W. (No. 2, Pl. LII), the rocks below 1,865 feet are made up largely of limestone and sandstone, with shale practically absent from the section below 2,630 feet. Granite has been reported from a few test holes drilled within this zone below the thick bodies of limestone.

In the test hole in sec. 35, T. 6 S., R. 5 W. (No. 2, Pl. LII) a little less than 900 feet of rocks were found between the base of the "Red Beds," at 977 feet below the surface, and the top of the predominant limestone-sandstone series, at 1,865 feet. Over three-fourths of this interval is composed of shale; it contains a number of sands that are between 5 and 60 feet thick, a few thin limestones, and several black shales and limestones. This association of thick sands with a predominance of shale and with a few beds of black shale or black limestone is about the combination that the oil geologist ordinarily looks for in a prospective oil and gas field. The beds between 977 and 1,865 feet in the test hole in sec. 35, T. 6 S., R. 5 W., therefore constitute the critical part of the section, which should be carefully tested in drilling for oil or gas within the area outlined by Plate LII. The log of this same test hole shows some shale between 1,865 and 2,709 feet, and test holes drilled in Montague County, Tex., to the south, show black shale closely associated with sandstone as deep as 2,500 feet. Therefore, this part of the section also should be tested, but the sands are not as promising as they are in the overlying beds described above. Below a horizon corresponding to the top of the thick limestone found at 2,709 feet in the test hole in sec. 35, T. 6 S., R. 5 W., the chances are believed to be too poor to warrant drilling these beds, and it is recommended that future test holes in this area be drilled to a depth corresponding to this horizon but not below it. The beds below 2,709 feet in the test hole in sec. 35, T. 6 S., R. 5 W., are probably of Ordovician age; they contain no shale but are made up largely of siliceous limestone.

Although it is particularly difficult to make long-distance correlations in this area because of the unusual subsurface conditions and the likelihood that the formations below the surface here are different in thickness and character from their surface exposures, it is still possible to make certain tentative correlations that may be used until detailed examination of the fossils which may be found in the drill cuttings or other evidence makes these or other conclusions more certain. The Petrolia oil and gas field, in northern Clay County, Tex., is the nearest producing field to the area outlined on Plate LII, and this field has been studied and described by both the United States Geological Survey and the Texas Geological Survey. Generalizing the logs at Petrolia and in southern Jefferson County causes certain characteristics to stand out that are common to both localities. At Petrolia the base of the "Red Beds" is found in many logs at about 1,200 feet below the surface, the principal oil and gas sands are usually found between 1,500 and 1,750 feet, and the top of the thick limestone series is about 275 feet lower. In southern Jefferson County the test holes drilled near Red River show the base of the "Red Beds" to be close to 1,000 feet below the surface; between

1,300 feet and 1,600 feet there are a number of thick sands which are associated with black shales and which have produced shows of gas in a number of test holes, shown on Plate LII, and the top of a thick sandstone-limestone series in the test hole in sec. 35, T. 6 S., R. 5 W. is taken to be at 1,865 feet below the surface.

The interval between the base of the "Red Beds" and the top of the series producing oil sands at Petrolia is in round numbers 300 feet, and this same figure may be used for the interval between the base of the "Red Beds" and the series of sands associated with black shales encountered in the test holes drilled in southern Jefferson County. The interval between the base of the series of producing sands at Petrolia and the top of the thick limestone-sandstone series is about 250 feet, and the interval between the base of the sandstone series associated with black shales and the top of the thick limestone-sandstone series found in the test hole in sec. 35, T. 6 S., R. 5 W., is 267 feet. It should be recognized that the base of the "Red Beds" is not a clean-cut horizon, but it can be used for correlation by grouping together a number of well logs in a locality and determining a general depth at which this horizon is reached. It should also be recognized that even though these intervals agree fairly well, it should be possible to make more conclusive correlations through the study of fossils that may be found in the samples of the drill cuttings.

From the data at hand the most plausible correlation between the logs in the Petrolia field and the test hole in sec. 35, T. 6 S., R. 5 W. is as follows:

Depth, in feet, of certain horizons at Petrolia, Tex., and in Jefferson County, Okla.

	Petrolia, Tex. (generalized section).	Test hole in sec. 35, T. 6 S., R. 5 W., Okla.
Base of "Red Beds".....	1,200±	1,000±
Top of series of most promising sands.....	1,500.....	1,300.....
Base of series of most promising sands.....	1,750.....	1,600.....
Top of limestone-sandstone series.....	2,010.....	1,865.....
Top of Ordovician.....	Between 2,600 and 2,800?	2,700±

As no determinations of fossils or studies of samples from the test hole in sec. 35, T. 6 S., R. 5 W., have been made, the correlation of the thick limestone found at 2,709 feet with the Ordovician rocks reported in the Petrolia field must be considered at present questionable.

According to Udden and Phillips¹³ the principal oil sands in the Petrolia field (1,500 to 1,750 feet below the surface) are of Cisco age and therefore if the above correlation is accepted the sands and shales

¹³ Udden, J. A., and Phillips, D. McN., *Geology of the oil and gas fields of Texas: Texas Univ. Bull.* 29 p. 90, 1912.

between 1,300 and 1,600 feet in the test hole in sec. 35, T. 6 S., R. 5 W., are also to be assigned to the Cisco. As the top part of the Cisco is red the line between the Wichita and the Cisco would be at some horizon between the surface and 1,000 feet below the surface. The age of the rocks between 1,865 and 2,709 feet can not be established until more detailed fossil determinations are made, and they are tentatively classified here as probably representing rocks of Canyon and Strawn age. The rocks below 2,709 feet are tentatively assigned to the Ordovician. The log of the test hole drilled in sec. 35, T. 6 S., R. 5 W., is graphically shown on Plate LII for use as a type log in this district.

STRUCTURAL FEATURES.

The structure of a prospective oil and gas region is of great economic importance, because it is generally conceded that certain structural features such as anticlines and domes serve to trap the oil and gas in pools where the sand is uniform and other conditions are favorable. The determination of the structure in a region which is known to be underlain by formations that carry oil in other localities but in which there has been very little drilling is particularly desirable, because in such a region the structure is the dominating factor in the selection of locations of test wells for oil and gas.

REGIONAL STRUCTURE.

It is difficult to say what is the normal or regional dip of the surface rocks in southern Oklahoma south of the Arbuckle and Wichita mountains. A clue to this is given by Aurin,¹⁴ who has shown the depth to the base of the "Red Beds" over central and western Oklahoma. Although it is known that the base of the rocks that are red is not parallel to a stratigraphic horizon, it is probable that this contact between red and nonred rocks follows in a general way the major structural features of central and western Oklahoma. As shown on Plate I in Aurin's paper this contact dips north in the southern part of Jefferson County and southwest in the northern part. It is probable that this is a close approximation of the general structure of the region, for in general the rocks of Pennsylvanian age dip toward the south and southwest from the Arbuckle and Wichita mountains on the southern flanks of these mountains, and in northern Texas the normal dip of the Pennsylvanian rocks is toward the northwest.

Another factor that is of interest in the consideration of the general structure of this region is the reported occurrence of Ordovician rocks and granite in the zone extending across southern Jefferson County, Okla., and into northern Clay and Cooke counties, Tex. From the evi-

¹⁴ Aurin, Fritz, Oklahoma Geol. Survey Bull. 30, 1917.

dence at hand it looks as if there is a buried ridge of older rocks along this zone, for deep test holes drilled to the north and south of it have reported neither Ordovician rocks nor granite. As this is an economic paper and as it is believed that more detailed studies of the fossils in the drill cuttings should be made before sound conclusions can be reached, this feature is discussed here only in so far as it has a bearing on the oil and gas possibilities of the area under consideration. A buried ridge of rocks made up of such rigid materials as limestone and granite, on which younger and less rigid sediments were unconformably deposited, should exert a strong influence on the folding of these younger beds when they were subjected to the stresses that produced folding. It might be logically assumed that local folding would be concentrated along this zone and that the general structure of this zone of local folding in the younger rocks would be that of an uplift. This might be classed as favorable general structure for the accumulation of oil and gas. The Petrolia field appears to be in this zone, and the Burkburnett and Electra fields may possibly be along parallel zones of folding, slightly offset from the zone in which the Petrolia field lies.

It might be argued that the ridge of older rocks represents an uplifted zone in these older rocks and that movements along old lines of uplift have produced folds in the overlying Pennsylvanian and Permian rocks that parallel the old lines of folding in the Arbuckle Mountains. It would be very reasonable to assume that an uplift of the magnitude of that which produced the Arbuckle Mountains would be paralleled by other uplifts, perhaps of lesser magnitude, and it would not be surprising to find these uplifts arrayed en échelon or in parallel arrangement, slightly offsetting one another. It may be concluded that the area outlined on Plate LII is in a region where it would be reasonable to expect to find anticlines and domes favorable for the accumulation of oil and gas, provided proper subsurface conditions exist.

LOCAL STRUCTURE.

GENERAL CONDITIONS.

It was impossible to map the structure of the "Red Beds" over the entire area treated in this report, because in many places there are no hard ledges exposed that could be traced. The absence of exposures of the hard ledges in the "Red Beds" is due partly to the fact that these beds are in places covered by more recent deposits, such as the deposits of sand northeast of Terral and the dune sand and alluvium bordering Red River, and also to the fact that over much of the area the ground is not dissected enough to produce very good outcrops of these hard ledges. All exposures of hard ledges that could be followed for a reasonable distance were mapped, and

the direction and amount of dip of these beds are shown on Plate LII by means of structure contours. These contours have an interval of 10 feet and in the eastern part of the area are so drawn as to show the elevation above sea level of a theoretical bed 350 feet below the top of bed C (fig. 49 and Pl. LII). The contours based on conclusive field evidence are drawn as solid lines; if the evidence is inconclusive the contours are dashed; and the dotted contours are not based on field evidence but are sketched in between areas where the dip is known.

In classifying the localities in an area as to their relative prospective oil and gas value the localities where the rocks have been locally folded into anticlines and domes should receive first consideration if the other factors are equal. Therefore, the anticlines shown by structure contours on Plate LII are briefly described below.

SEAY ANTICLINE.

The Seay anticline is in the south-central part of T. 6 S., R. 5 W., and the north-central part of T. 7 S., R. 5 W. The east dip of this anticline amounts to more than 170 feet within a distance of a little over 2 miles, and fairly well defined dips have been mapped on its northern and western flanks. No dips to the south from the crest of this anticline are shown on Plate LII, and therefore the anticline is not known to be closed.

GROGAN ANTICLINE.

The Grogan anticline covers parts of secs. 18 and 19, T. 7 S., R. 5 W., and parts of secs. 13 and 24, T. 7 S., R. 6 W. The western flank of the anticline has a relatively very steep dip toward the southwest, showing on Plate LII a drop of 160 feet within half a mile. The dips on the eastern and northern flanks of the anticline are relatively gentle, and there is a suggestion of a structural nose on its eastern flank. Toward the northwest, in secs. 13 and 14, the rocks are not well enough exposed to establish structure contours.

RED CREEK ANTICLINE.

The axis of the Red Creek anticline has a northeasterly trend and roughly bisects sec. 26, T. 6 S., R. 6 W. On the whole the dips of this anticline are rather poorly defined, but there is enough field evidence to show a well-defined northwest dip, a poorly defined south or southeast dip, and a fairly well defined southwest dip.

OTHER FOLDS.

East of the town of Ryan the rocks appear to be bowed up into a broad structural arch. On the whole the field evidence is rather

poor, and on Plate LII many of the structure contours are dotted and dashed, indicating doubt as to the correct interpretation of the structure over part of the area. Secs. 15, 16, 21, and 22 probably cover the crest or top of this broad anticlinal feature.

Over much of the area here considered it was impossible to map the structure, as is represented by the lack of structure contours in parts of Plate LII. With regard to that part of the area where the structure has been mapped it may be stated that the structure is either favorable or not favorable for the accumulation of oil or gas, but with regard to the area where the structure is unknown the geologist must confess his inability to classify the different localities as to their relative prospective oil and gas value and can only give the general rating of the entire region.

SUGGESTIONS TO PROSPECTORS.

GENERAL RATING OF THE AREA.

Anyone who contemplates investing funds in a prospective oil and gas area wishes to know whether the area as a whole is a "likely oil country," and if it is he wishes to know what part or parts of the area give the greatest promise for oil and gas production.

The most obvious factor in classifying an area is its distance from and geographic relation to productive oil and gas pools. Other conditions being equal, an area that is relatively close to and surrounded by producing oil and gas pools gives greater promise than an area that is not so geographically located or one that is relatively far from producing territory. The area treated in this report is about 18 miles southwest of the Healdton oil field, Okla., 25 miles southeast of the producing oil and gas wells near Walter, Okla., and about 18 miles due east of the Petrolia oil and gas field, Tex. No commercial production of oil or gas has been reported within a reasonable distance south or east of the area.

A factor that is more important than the geographic location is the relation of the rocks below the surface in the area under discussion to the rocks in the near-by oil and gas fields. It is probable that the same beds which carry oil and gas in the Petrolia field, to the west, underlie the surface in southern Jefferson County at depths that can be easily reached by the drill. Although no attempt has been made to correlate the oil sands of the Healdton and Walters fields with the subsurface rocks in southern Jefferson County, the oil sands in these producing fields are probably represented in southern Jefferson County by beds of the same age which are not too deep to be reached by the drill.

To summarize briefly, the area outlined on Plate LII is underlain by beds at relatively shallow depths which carry productive oil and

gas sands in other areas near by, and the general structure is favorable, but the area is not very close to any commercially productive oil and gas field. It might properly be classed as a promising prospective oil and gas area in which there are good speculative chances but in which the business risk is relatively high compared to that involved in drilling within a mile or so of producing wells in an area of favorable structure. On the whole, the parts of anticlines recommended below should be classed as good risks, and as there is no good reason to condemn absolutely any part of the area there is a chance that, owing to irregular sand conditions, oil or gas may be obtained from a test hole drilled at any other point within the area. The difference is that tests on the recommended anticlines are good risks, but tests at random are not; consequently the importance of properly locating test wells on these anticlines is obvious.

RECOMMENDATIONS.

Four anticlines are shown on Plate LII and described above—the Grogan anticline, the Seay anticline, the Red Creek anticline, and a poorly defined anticline east of the town of Ryan. The territory covered by these anticlines should be regarded as the most promising prospective oil and gas territory within the area mapped, and of the four the Grogan anticline should receive the highest rating. That part of the Seay anticline shown by structure contours on Plate LII has probably been tested, but it is possible that the top part of this anticline or dome is still farther south and has not been tested. The Red Creek anticline is not so large or so well defined as the Grogan anticline, and consequently it should be given a lower rating. On the meager evidence in hand, the anticline east of the town of Ryan should be regarded as only slightly more promising than the surrounding country and much less promising than the other anticlines described.

The Grogan anticline is well worthy of a test to a depth of 2,800 feet, and the test hole should be drilled a quarter of a mile south and 300 feet east from the northwest corner of sec. 19, T. 7 S., R. 5 W. This anticline is believed to be distinctly promising because (1) it represents the highest area structurally within the boundaries of the area shown on Plate LII according to the available information; (2) there is an unusually large gathering ground around it; (3) the shape of the contours suggests that the structural top of the anticline may be very close to the recommended location. The most promising sands should be encountered between 1,300 and 1,700 feet below the surface, but other sands that may produce oil or gas may be found to a depth of 2,800 feet.

As two dry holes have been drilled on the Seay anticline deep enough to test the most critical sands, additional tests on the anticline as

mapped on Plate LII hardly seem warranted. As water was reported in several of the deep sands in the test hole drilled in sec. 3, T. 7 S., R. 5 W., it seems likely that the dips indicated on the map are part of an anticlinal nose that plunges to the north. If they are, the structural nose may open into a structural dome toward the south, or the dip may change into a monoclinical dip. In any event no new tests on this anticline are recommended unless new development changes the general rating of the region or additional information is obtained on the structure to the south.

As the structure of the Red Creek anticline is rather poorly defined it is difficult to determine definitely whether the dips to the northeast close this fold. From the information at hand the highest part structurally of the anticline is about 1,500 feet north of the center of sec. 26, T. 6 S., R. 6 W. and this should be the location of the first test well, if this anticline is drilled. The most promising sands should be expected between 1,500 and 1,800 feet below the surface, but if commercial quantities of oil are not found at a lesser depth the hole should be drilled to a total depth of 2,900 feet. Although the structure is rather poorly defined and the reverse dip is not very large, this reverse dip to the south and southwest is believed to be strong enough to justify a test at the location recommended above, unless future drilling changes the general rating of this region. It should be remembered that this anticline has a lower rating than the Grogan anticline.

The anticline east of Ryan is not recommended for testing, but if this area should be drilled a test should be made near the southeast corner of sec. 16, T. 6 S., R. 7 W. The chance of obtaining commercial quantities of oil or gas here, however, would be only slightly better than in the surrounding country.

CONCLUSIONS.

It should be emphasized that the recommendations in this paper do not guarantee that oil or gas will be found at the localities described. Experience has proved, however, that the chance of failure, particularly in regions far removed from producing wells, is materially reduced if the localities for tests are selected according to recommendations made after careful study of the available geologic information.



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Bulletin 726—G

THE LACASA AREA, RANGER DISTRICT NORTH-CENTRAL TEXAS

BY

CLARENCE S. ROSS

Contributions to economic geology, 1921, Part II
(Pages 303-314)

Published December 23, 1921



WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

CONTENTS.

	Page.
Introduction.....	303
Stratigraphy.....	304
General character of exposed rocks.....	304
Key beds.....	306
Names.....	306
Ranger limestone.....	306
Home Creek limestone.....	306
Gonzales limestone.....	307
Bunger limestone.....	308
Structural features.....	308
General structure.....	308
Areas of favorable structure.....	309
Hagaman terrace.....	309
Veale anticline.....	309
Adams anticline.....	310
Gonzales dome.....	311
Atkins anticline.....	311
Areas of unfavorable structure.....	312
Wells.....	313

ILLUSTRATIONS.

	Page.
PLATE LIII. Map showing geologic structure in Lacasa area, Tex.....	308
LIV. Selected well records in Lacasa area, Tex.....	314
FIGURE 50. Key map of north-central Texas showing location of Lacasa area..	303
51. Columnar section of rocks exposed in Lacasa area, Tex.....	305
52. Key map of Lacasa area, Tex., showing locations of wells whose logs are given in Plate LIV.....	312

THE LACASA AREA, RANGER DISTRICT, NORTH-CENTRAL TEXAS.

By CLARENCE S. ROSS.

INTRODUCTION.

The area 6 miles square described in this report lies in the Ranger oil district, in the southeastern part of Stephens County, Tex., its south line corresponding approximately with the south border of the county and its east line lying 6 miles west of the east border of the county. (See fig. 50.) The village of Lacasa, after which it has been named, is near its northeast corner. Strawn, on the Texas & Pacific

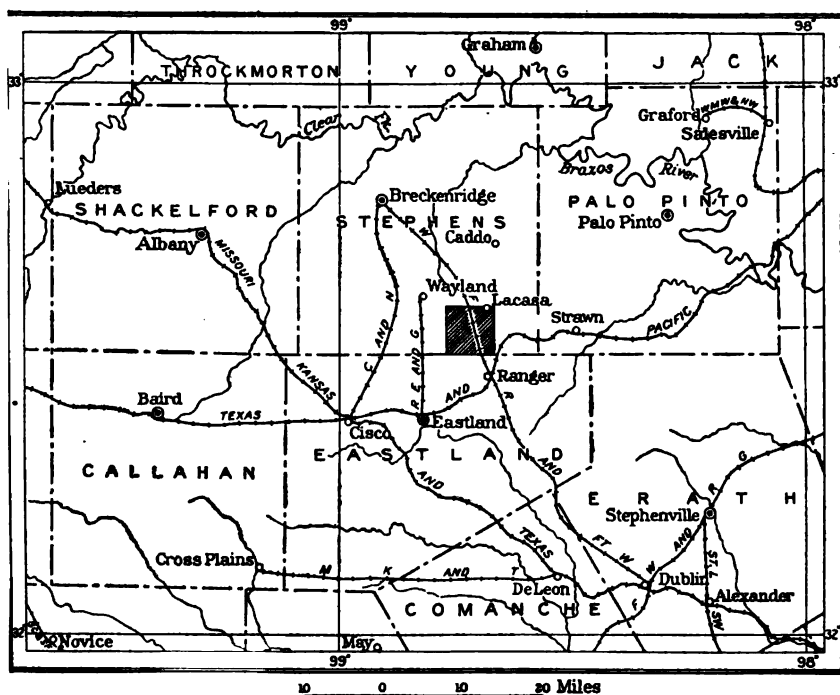


FIGURE 50.—Key map of north-central Texas showing location of Lacasa area.

Railroad, is about 10 miles east of its east border, and Ranger, on the same road, lies 4 miles south of the south border. Caddo Creek drains the eastern part of the area and flows in a general northeasterly direction, crossing the north line not far from the village of Lacasa.

Gonzales Creek and its tributaries drain the western part of the area and flow in a northwesterly direction, leaving the area near its northwest corner. The country is gently rolling, and the maximum relief is about 320 feet. The eastern and northern parts are the most rugged, and the southern part is characterized by high sand flats. About one-third of the area is covered by timber, in which scrub oak predominates.

The field work was done during April and May, 1919, by the writer, assisted by W. G. Argabrite. Locations and elevations for working out the geologic structure were determined by plane table and telescopic alidade.

For convenience in reference the Lacasa area has been arbitrarily divided into 144 blocks by 12 north-south coordinates and 12 east-west coordinates, as shown on Plate LIII. Beginning at the upper left-hand corner of the area the blocks are numbered consecutively toward the east and lettered consecutively toward the south. Thus K-5 designates a block 11 units south and 5 units east from the northwest corner of the area, or, as each block is half a mile square, $5\frac{1}{2}$ miles south and $2\frac{1}{2}$ miles east from the northwest corner.

STRATIGRAPHY.

GENERAL CHARACTER OF EXPOSED ROCKS.

The rocks exposed at the surface in the Lacasa area, having an aggregate thickness of about 600 feet, are illustrated graphically in figure 51. The oldest are Pennsylvanian; above these are Cretaceous rocks; and still younger beds are probably Tertiary. Local unconformities occur within the Pennsylvanian, and profound unconformities between the Pennsylvanian and Cretaceous and between the Cretaceous and the Tertiary(?).

Pennsylvanian rocks are exposed in the northern and eastern part of the area, those in the northern and northeastern parts belonging to the Cisco formation and those along the eastern border to the Canyon formation. The Canyon formation is characterized by massive limestones with intervening shales and sandstones. Shales predominate in the Cisco formation, but thin limestones are present and massive sandstones form considerable part of the formation.

After the deposition of the Pennsylvanian beds they were subjected to profound erosion, and after the lapse of a long period of geologic time the Trinity sand, of Lower Cretaceous age, was deposited unconformably upon them. The Trinity consists of conglomerates, sandstones, unconsolidated sands, siltlike material, clay, and some siliceous limestones, the whole very much cross-bedded. The pebbles of the conglomerate consist partly of such local material as limestone, sandstone, and shale, but most of them are foreign quartzite, vein quartz, or chert. Where the conglomerate has withstood

the disintegrating action of weathering the spaces between the pebbles are filled with fine sand, which is firmly cemented with calcium carbonate. Over most of the area where the conglomerate is present, however, it has broken down into a mass of loose sand with pebbles and cobbles scattered through it, and the original nature and appearance of the indurated bed must be determined from small fragments that have withstood disintegration and from a few good exposures where the Cretaceous rocks are protected by a resistant layer of more recent material.

The conglomerate that caps the hills over much of the area and lies unconformably above the Cretaceous beds contains silicified wood, but no fossils have been found that permit a definite determination of its age.

It has been provisionally assigned to the Tertiary, but it is possibly of the same age as beds that have been called "Lafayette" in other parts of Texas.¹ It is made up of quartzite, quartz, and chert sand grains and pebbles reaching maximum dimensions of several inches. The only fragments of local rocks that have been recognized are rounded boulders of Trinity conglomerate. These materials are similar to those of the Trinity and no doubt have been derived in part or wholly from that formation, thus making it difficult to distinguish the two conglomerates. The Trinity has a cement of calcium carbonate, but the later conglomerate has a cement of chalcedony which gives it great resistance to weathering. The pebbles from the Trinity are waterworn but are not well rounded.

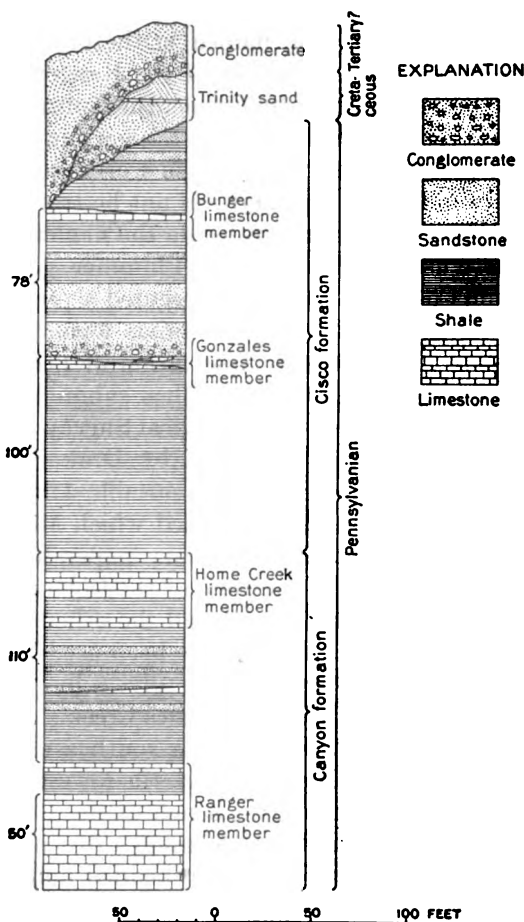


FIGURE 51.—Columnar section of rocks exposed in Lacasa area, Tex.

¹ Udden, J. A., Baker, C. L., and Böse, Emil, Texas Univ. Bull. 44, p. 91, 1916.

Those from the later conglomerate show a greater degree of attrition, and 90 per cent of the pebbles over an inch in diameter are dreikanterers or show other evidences of wind erosion, thus presenting clear evidence that these beds were deposited under desert conditions.

KEY BEDS.

The beds that have been useful in mapping the geologic structure of the Lacasa area, named in the order of their deposition, are the main and upper benches of the Ranger limestone, the base and top of the Home Creek limestone, the Gonzales limestone, a fossil-bearing zone just above it, and the Bunger limestone. The sandstones have proved to be of little value in working out the geology, as they have very indefinite tops and can not be traced continuously.

Names.—So far as possible the names given to the beds have been those used by Frederick B. Plummer, geologist of the Roxana Petroleum Co. Mr. Plummer presented a preliminary paper^{1a} on the stratigraphy of the Pennsylvanian formations of north-central Texas before the American Association of Petroleum Geologists at Dallas, Tex., in March, 1919, and has submitted a later unpublished paper to the United States Geological Survey for suggestions. In the later paper the names proposed by Drake² for the Colorado coal field have been used wherever suitable and where definite correlations have been possible. The bed which Mr. Plummer called "Eastland limestone" in the preliminary paper has now been correlated with the Home Creek limestone of the Colorado coal field. North-central Texas is the type area for all the other beds described in the present paper, and local names have been used by Mr. Plummer. The name Gonzales limestone is here given by the writer to the limestone exposed in the bed of Gonzales Creek.

Ranger limestone.—In the southeastern part of the Lacasa area occurs the Ranger limestone, the lowest bed appearing at the surface in the area. The main bench of the Ranger is a light-gray massive limestone 50 feet thick, forming a distinct and easily traceable scarp. The topmost ledge is a thin-bedded buff limestone 4 feet thick lying 16 feet above the main bench, from which it is separated by 12 feet of shale.

Home Creek limestone.—The Ranger limestone is overlain by about 70 feet of shale containing several thin-bedded calcareous sandstones and lenticular limestones. The only prominent lens of limestone forms a ledge lying 39 feet above the top of the Ranger. In the northern part of the Lacasa area it is 3 feet thick, but it thins toward the south and is entirely absent at the southern border. A series of alternating limestones and shales extending from 70 to 110 feet above

^{1a} Plummer, F. B., Am. Assoc. Petroleum Geologists Bull., vol. 3, pp. 132-145, 1919.

² Drake, N. F., Report on the Colorado coal field: Texas Geol. Survey Fourth Ann. Rept., pp. 357-446, 1893.

the top of the Ranger limestone and locally known as the "Caddo lime" has been correlated with the Home Creek limestone by Plummer. Drake did not interpret the Home Creek as the top of his Canyon division in the Colorado coal region, but the top of the Home Creek appears to be the dividing line between the Cisco and the group of heavy limestones to which Cummins³ gave the name Canyon in his report on the geology of the northern coal region, of which this area is a part. In the southeastern part of the Lacasa area the lowest limestone of the Home Creek member forms a continuous scarp about 76 feet above the top of the Ranger. Above this ledge are several benches of fine-grained light-gray limestone without fossil-bearing beds that can be used as horizon markers. No good section of the upper part of the Home Creek can be measured in this region, but by comparison of the structure contours the top is found to be about 110 feet above the top of the Ranger.

Gonzales limestone.—Above the Home Creek limestone lies a series of shales about 96 feet thick, which in the Lacasa area have been cut away by Caddo Creek to form a large valley. The east side of this valley is the alluvium-covered dip slope of the Home Creek limestone. The west side is a scarp capped by a limestone, which is also exposed along the headwaters of Gonzales Creek, and from these exposures it is herein named the Gonzales limestone member of the Cisco formation.

The Gonzales limestone occupies a position in the geologic section corresponding closely with that of a bed occurring in the vicinity of Jacksboro, to which Plummer has given the name Jacksboro limestone, and both beds are characterized by unusual numbers of *Campophyllum*. Plummer states that the Jacksboro thins toward the south and disappears 10 to 15 miles southwest of Jacksboro; and the writer finds that the Gonzales thins toward the north and disappears near the north border of the Lacasa area, leaving an interval of nearly 40 miles over which neither bed has been traced. For this reason a local name has been used for the limestone found in the Lacasa area.

Although the Gonzales limestone is thin or entirely missing in the northern part of the area it thickens rapidly toward the south and reaches a maximum thickness of about 4 feet. It is a coarse-grained dark-gray limestone containing large numbers of *Campophyllum*, and locally a thin shaly limestone carrying many specimens of *Myalina subquadrata* lies 8 feet above it. The interval between the top of the Home Creek limestone and the top of the Gonzales limestone can not be measured directly in this region but is about 100 feet. The top of the Gonzales is marked by a slight unconformity. In most of the area it is overlain by only a few inches of shale, above

³ Cummins, W. F., Geology of northwest Texas: Texas Geol. Survey Second Ann. Rept., p. 374, 1890.

which lies a very massive bed, the base of which is an intraformational conglomerate containing ferruginous clay pebbles. This grades into a conglomerate composed of light-colored chert pebbles with quartz sand filling the interstices, and this conglomerate in turn grades into a normal sandstone whose top is about 20 feet above the top of the limestone. A second bench of sandstone slightly less massive than the first lies about 22 feet higher still. All the sandstones thicken from the northern to the southern part of the region. Shales predominate in the succeeding 31 feet, but a thin-bedded calcareous sandstone 16 feet above the second bench of sandstone and richly fossiliferous limestone lenses are common in the northern part of the area. Thin coal bands are locally present near the base of the shale.

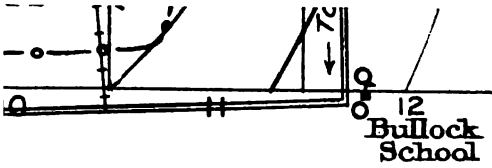
Bunger limestone.—About 78 feet above the top of the Gonzales limestone lies a very persistent limestone which has been called by Plummer the Bunger limestone. It is light gray, contains but few fossils, and forms a bench 2 to 5 feet thick. It makes a low but easily traced escarpment facing toward the southeast in the north-central part of the area and occurs along both sides of Gonzales Creek and its tributaries in the northwestern part. Above it is a series of alternating shales and sandstones containing chert conglomerates, and the highest bed in the Lacasa area is a sandstone lying about 60 feet above the Bunger.

STRUCTURAL FEATURES.

GENERAL STRUCTURE.

The geologic structure described below and portrayed on the contour map (Pl. LIII) is determined by observations on the beds of Pennsylvanian age. Although in some places the attitude of the overlying Cretaceous and Tertiary (?) rocks can be determined, it is believed that most of the deformation which affected the oil-bearing beds took place before Cretaceous time, and that observations on the Cretaceous and post-Cretaceous beds will not be of assistance in determining the location of deep-lying folds that may be of economic importance.

The general structure of the Lacasa area conforms to that of the Pennsylvanian beds of north-central Texas as a whole and shows normal northwesterly dip averaging about 50 feet to the mile. The structure contours shown on Plate LIII are based for the most part upon observations on beds exposed at the surface; but in the southern and central parts of the area rock outcrops are lacking, and well records have been used wherever available to determine the position of key beds. The structure contours are drawn on the surface of a theoretical bed lying approximately 260 feet below the top of the highest bed of the Ranger limestone. The position of the contours shows



TEXAS

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by broken lines is open to some doubt, owing to the lack of exposures of Pennsylvanian beds.

A study of the oil production in the Ranger field shows that the best yields of oil are obtained in areas where the surface beds show terraces, noses, or dipping anticlines. These surface features commonly mark much more sharply accentuated folds in the oil-yielding beds, and a surface fold that shows no closure may overlie a subsurface fold with a large closure.

AREAS OF FAVORABLE STRUCTURE.

In the Lacasa area there is a large pitching terrace in the southeastern part, a pitching anticline in the northwestern part, and a group of three noses or pitching anticlines in the central and northern parts. These features are described below.

HAGAMAN TERRACE.

In the Hagaman terrace, in the extreme southeast corner of the Lacasa area, the rocks dip to the northwest at only about half their normal rate. It extends eastward into the Wiles area and southward into the East Ranger area, and in the Lacasa area it covers all the territory south and east of a line running between squares G-12 and L-9. (See Pl. LIII.) It is marked by a pronounced moderation of the regional dip east of the line mentioned, with correspondingly steep dips west of the line. East of the "step" of the terrace, in the Wiles and East Ranger areas, the beds rise sharply southeastward. Such folding as has taken place has been parallel to the strike of the beds, and there is nothing in the Lacasa area to indicate cross folding in any other direction.

The terrace had been fairly well outlined by producing wells at the time the field work was done (May, 1918), and a great many test holes were being drilled. To judge from conditions known to prevail elsewhere in the Ranger district, the folding in the oil sands is more pronounced than that at the surface, and oil will probably be obtained outside the limits that would be set were surface structure alone considered. The work of comparing subsurface and surface folding has not yet been carried far enough to justify positive statements regarding the probable extent of producing area, but it appears probable that oil will be found farther to the west of the area of low dip than to the east of it, as in this particular part of the Ranger district preliminary work indicates that the deep-lying folds are likely to be offset to the west with respect to surface folds.

VEALE ANTICLINE.

In the northeastern part of the Lacasa area alluvium along Caddo Creek prevents complete mapping of the surface beds, but those that

are traceable indicate a small pitching anticline beginning about a mile southeast of Lacasa and extending in a northwesterly direction into the Necessity area, to the north. This fold is here called the Veale anticline. Oil is being produced in commercial amounts from the Veale sand at a depth of about 3,800 feet in several wells in this area, and the reported initial daily production ranges from 80 to about 700 barrels. The probable extension of the field can not be foretold until the areas to the north and northeast have been mapped, but new wells can be expected north and west of those now developed. The Veale sand is within the Marble Falls limestone.

ADAMS ANTICLINE.

The Adams anticline, which runs in a northwesterly direction across blocks B-6, B-7, A-5, and A-6 (see Pl. LIII) into the Necessity area, to the north, forms one of the most promising undeveloped oil localities in the region. On the east the anticline is bordered by a shallow pitching syncline in blocks B-9, A-8, and A-9. On the southeast it merges into a large flat. On the south a shallow pitching syncline separates it from the Gonzales dome. The continuation of this anticline into the Necessity area has not yet been mapped (July, 1919).

The Adams gas well, in block A-9, on the crest of the anticline, reaches a gas sand at a depth of 2138 feet, but the deeper sands have not been tested in this locality. Wells drilled east and west of the Adams well along the north border of the area allow a study of the subsurface beds in this anticline. The Maxwell well No. 1 of the Texas & Pacific Co., 1 mile west of block B-1, was dry at a depth of 3,833 feet. The distance between this well and the Adams well is $4\frac{1}{2}$ miles, and both the surface beds and the subsurface beds show a westerly dip between these points. Along the axis of the anticline, $1\frac{1}{4}$ miles southeast of the Adams well, is the Haney well, which was practically dry at a depth of 3,527 feet. Between these two points the surface beds show a slight northwesterly dip, and the subsurface beds dip in the same direction at about the same rate.

The Bradford well, in block A-10, $1\frac{1}{4}$ miles northeast of the Haney well, had not quite reached the producing sands at a depth of 3,490 feet when the field examination was completed. This well and the Haney well are approximately on the strike of the surface beds, but the subsurface beds show a northeasterly dip that gradually increases with increasing depth. The top of the Smithwick shale, at a depth of about 3,050 feet, shows a reversal of dip of about 80 feet in $1\frac{1}{4}$ miles. The Bobo well, about half a mile south of the Bradford well, in block B-10, is dry at a depth of 4,140 feet. It is slightly up the dip of the surface beds from the Bradford well, but at the top of the Smithwick shale there is a southerly dip of 90 feet in half a mile. The Veale well

is 1 mile east of the Bobo well, and between these two points both the surface beds and the subsurface beds dip normally to the west.

These data indicate that the subsurface structure of the Adams anticline is marked by an eastern flank dipping sharply to the east, beyond which there is a sharp syncline occupying approximately the position of the syncline trending northwest from the Bobo well that has been mapped on the surface beds. Favorable locations for test wells lie along the crest of the anticline north and west of the Adams gas well.

GONZALES DOME.

Just east of Gonzales Creek in blocks C-4, C-5, D-4, and D-5 (see Pl. LIII) lies a low anticline with about 15 feet of closure that has been called the Gonzales dome. It is separated from the Adams anticline by a shallow westward-pitching syncline. On the south is a sharp westward-pitching syncline, and on the east lies a southern continuation of the flat that lies east of the Adams anticline.

The axis of this fold trends almost due west, diverging a few degrees from parallelism with that of the Adams anticline. The flexure is not nearly as extensive in an east-west direction as the Adams anticline, to the north, and the Atkins anticline, to the south, but some indication of it can nevertheless be detected $1\frac{1}{2}$ miles west of the center of the dome.

No test holes have been drilled either on or near the axis of this fold, so its possibilities for oil production are not known. Furthermore, such test holes as were being drilled near by while the field work was in progress were not located advantageously with respect to the surface structure, and their failure would not condemn land nearer the axis of the flexure, although their success would make the territory that seems structurally more favorable appear particularly promising. Probably the most favorable location for a test well lies in the northeast corner of block C-4.

The outline of the Gonzales dome as shown on the structure map was controlled largely by elevations on the Bunger limestone, which furnished a reliable datum.

ATKINS ANTICLINE.

A pitching anticline extends from blocks F-5 and G-5 westward toward the Atkins School, in block G-1, after which it has been named, and crosses into the Gunsight area, to the west, just beyond that school. The plunging axis trends approximately parallel to those of the Adams anticline and the Gonzales dome. The dips to the northwest and southwest are pronounced, but to the east the anticline merges gradually into the regional monocline.

At the time the examination was made no wells had reached the beds which elsewhere in this region have proved to be oil bearing,

and there is no hint as to the relation which the deep-seated structure may bear to that exhibited at the surface. However, a test drilling in block G-2, almost on the axis of the fold, and one in block F-1, on its northwest flank, should furnish a reliable indication of what may be expected in the way of production. The location of the well being drilled in block F-5 does not appear to be quite as favorable as the two mentioned above, but to judge purely from the surface indications this well should yield oil or gas. A comparison of the records of this well and those farther west will reveal the presence or absence of an easterly dip in the deep-lying beds. Should such a dip be present, the probability that there is a large anticline in the Smithwick and Marble Falls formations, underlying the strip covered by the Atkins, Gonzales, and Adams anticlines, should be considered. If this proves to be the case the synclinal areas that separate the surface folds can not be considered unfavorable for oil accumulation.

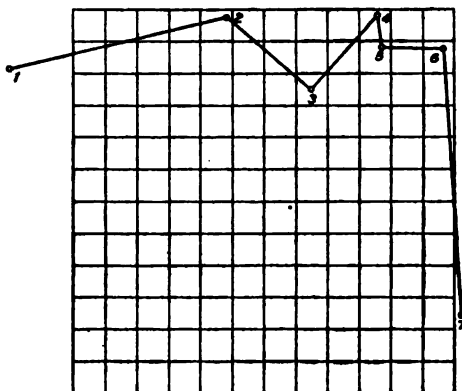


FIGURE 52.—Key map of Lacasa area, Tex., showing location of wells whose logs are given in Plate LIV.

The outline of the Atkins anticline was determined by elevations taken on outcrops of the Gonzales and Bunker limestones, which furnished reliable data upon which to base the structure.

AREAS OF UNFAVORABLE STRUCTURE.

Monoclines are not usually considered favorable localities for the accumulation of oil. In north-central Texas, however, the subsurface structure does not exactly correspond to that shown by the surface beds, and the conditions of the sand are known to have an important bearing on the accumulation of oil, and for these reasons the monoclinical areas that cover much of the Lacasa area can not be condemned as barren of oil.

The areas where marked synclines occur must be considered probably unfavorable for oil. The Bobo well, which was drilled in one such syncline, failed to yield either oil or gas, and the axis of this downwarp should be avoided in drilling. The syncline extending westward from the southeast flank of the Gonzales dome is also unfavorable. The syncline lying south of the Atkins School is not as sharp as the one last mentioned, but it is not nearly so favorable as the Atkins anticline, farther north.

WELLS.

The following table shows the names of some of the wells drilled or being drilled in the Lacasa area when it was examined, in May, 1919, the location of each well as indicated by the coordinates on Plate LIII, the character or status of the well, the name of the limestone bed nearest to the surface at the well, and the elevation of the well mouth. The logs of seven of these wells are given in Plate LIV, and the locations of the wells whose logs are given are shown in figure 52.

Wells in Lacasa area, north-central Texas.

Name.	Location.	Character or status.	Limestone bed nearest to surface.	Elevation (feet).
Adams No. 1, Texas & Pacific Co.	A-5.	Gas well.		1,584
Adams No. 2, Prairie Oil & Gas Co.	B-5.	Being drilled.	12 feet above Bunger.	1,578
Adams, J. J., No. 1.	G-11.	do.		1,471
Barnsley No. 1, Texas & Pacific Co.	A-12.	do.	4 feet above Caddo.	1,480
Beck No. 1.	I-8.	do.		1,537
Bobo No. 1, Texas & Pacific Co.	B-10.	Dry hole.		1,450
Bradford, E. T., No. 1, Texas & Pacific Co.	A-10.	Being drilled.		1,451
Brown, B. F., No. 1, Texas & Pacific Co.	E-8.	do.		1,581
Brown, B. F., No. 2, Prairie Oil & Gas Co.	F-9.	Abandoned.	2 feet above top of Gonzales.	1,500
Bullock School.	L-12.	Being drilled.		1,557
Collins, Marshall, No. 1, Magnolia Co.	L-9.	Oil well.		
Dempsey, Ben, No. 1, Prairie Oil & Gas Co.	K-11.	Being drilled.	76 feet above Ranger.	
Dempsey, Ben, No. 1, Prairie Oil & Gas Co.	J-9.	Oil well.		1,590
Denison lease, Brazos Co.	I-12.	do.	Ranger.	1,484
Dupre No. 1, Phillips Co.	H-8.	Being drilled.		1,544
Goforth, J. J., No. 1, Texas Co.	G-10.	do.	8 feet above top of Caddo.	1,549
Goforth, W. H., No. 1, Prairie Oil & Gas Co.	I-2.	do.		1,622
Graves No. 1, Prairie Oil & Gas Co.	G-2.	do.	35±3 feet below top of Bunger.	1,533
Haney No. 1, Texas & Pacific Co.	C-8.	do.	8 feet below top of Gonzales.	1,502
Higgins No. 1, Prairie Oil & Gas Co.	F-5.	Being drilled.		1,582
Hill No. 1, Gladstone Co.	G-10.	Oil well.	10 feet above top of Caddo.	1,548
Hill No. 2, Gladstone Co.	G-11.	Being drilled.	do.	1,568
Hill No. 1, Plains Oil Co.	H-10.	do.		1,506
Ingram lease, Parker & Monitor.	H-12.	do.	Ranger.	1,496
Jennings No. 1, Sun Co.	C-12.	Oil well.	Caddo.	1,512
Jones, C. P., No. 1, Texas & Pacific Co.	L-6.	Being drilled.	do.	1,494
Jones, L. G., No. 1, Texas & Pacific Co.	L-5.	do.		1,580
Lane No. 1, Humble Co.	G-10.	do.	6 feet above top of Caddo.	1,548
Lane No. 2, Humble Co.	G-10.	do.	do.	1,554
McCleskey No. 1, Texas & Pacific Co.	C-8.	Oil well.	20 feet below top of Gonzales.	1,492
Pace, J. I., No. 1, Texas & Pacific Co.	B-7.	Being drilled.		1,519
Pearce, D. Z., No. 2, Prairie Oil & Gas Co.	E-3.	do.	73±3 feet below top of Bunger.	1,484
Simmons No. 1, Sinclair Co.	D-2.	do.	5 feet below top of Bunger.	1,491
Suddarth No. 1, Texas & Pacific Co.	C-8.	do.	22 feet below top of Gonzales.	1,490
Terrill, C. E., No. 1, Magnolia Co.	L-8.	do.		1,609
Turner No. 1, Prairie Oil & Gas Co.	F-1.	do.	31 feet below top of Bunger.	1,485
Veale No. 1, Prairie Oil & Gas Co.	D-10.	Oil well.		1,589
Veale No. 1, Texas & Pacific Co.	B-12.	do.	Caddo.	1,501
Wells, J. W., Sinclair Co.	H-11.	Being drilled.	76 feet above Ranger.	1,564
Works, J. D., No. 1.	L-3.	do.		

Other wells near this area that were used in determining the structure are referred to the nearest coordinates on Plate LIII in the following table:

Wells near Lacasa area used in determining structure.

Name.	Location.	Character or status.	Elevation (feet).
Barker, Charles, No. 1, North Ranger area.....	L-5...	Being drilled.....	1,545
Veale No. 1, Sinclair Co., Wiles area.....	C-12...	Oil well.....	1,501
Wiles area.....	I-12...	Being drilled.....	1,598
Do.....	L-12...	do.....	1,494

NOTE.—In Plate LIV the location of well No. 2 (Adams No. 1, Texas & Pacific Co.) should be given as 3 miles west of Lacasa, and that of well No. 3 (Haney No. 1, should be given as Stephens County, Tex., without more specific designation.



TEXAS

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INDEX.

A.		Page.		Page.
Abo sandstone, distribution of, in			Black Rock Mountains, Ariz., domes	
New Mexico	181		near	104
Abo siding, N. Mex., formations			Bliss sandstone, San Andres Moun-	
penetrated at	219-220		tains, N. Mex., plate	
Acknowledgments for aid	8, 42,		showing	188
	89, 110, 278		Bloomington dome, Utah, descrip-	
Alamogordo, N. Mex., materials pen-			tion of	102-103
etrated near	227-228		favorable locality for drilling	
Alamosa Creek, N. Mex., map show-			on	107
ing structure in valley			Bluewater Canyon, N. Mex., plate	
of	266		showing	188
Animas Mountains, N. Mex., fea-			Bluewater Falls, N. Mex., Dakota	
tures of	275		sandstone at, plate	
Antelope Spring, Ariz., anticline			showing	196
near	107		Bluewater station, N. Mex., record	
Armiño, N. Mex., material pene-			of boring at	255
trated at	265		Bodega, N. Mex., materials pene-	
Arroyo Chupadero, N. Mex., features			trated at	221
of basin of	289		Bonine, C. A., work of	110
Atarque, N. Mex., Navajo and Da-			Boulders, glacial, in N. Dak., plates	
kota sandstones at,			showing	7, 141
plate showing	196		"Breaks," occurrence of	111
uplift at, plate showing	254		of the Little Missouri, near	
			Hans Creek, N. Dak.,	
			plate showing	112
			Brown oil well, near Dayton, N.	
			Mex., yield of	211
			Buchanan, N. Mex., formations	
			penetrated south of	199
			Bunn, Frank, work of	8
			Buttes in North Dakota, plates	
			showing	160
			in Squaw Creek valley, N.	
			Dak., plate showing	161
			on Hans Creek, N. Dak., plate	
			showing	140
			C.	
			Caddo oil sand, features of, in the	
			Cement oil field, Okla.	72
			Caddo Petroleum Co., analysis of oil	
			produced by	74
			Campbell, M. R., acknowledgment	
			to	3, 110
			Cannonball marine member of the	
			Lance formation, in	
			North Dakota, features	
			of	5-6, 7, 8-10
			on Heart River, N. Dak., plate	
			showing	7
			Carrizalillo Hills, N. Mex., features	
			of	273
			Carrizoso, N. Mex., materials pene-	
			trated at	228-229

	Page.		Page.
El Paso & Southwestern Railroad Co., wells bored by, in New Mexico. 227-229, 232-234		Fortuna Oil Co., analysis of oil produced by-----	74
Empire Gas & Fuel Co., log of well of, in Jefferson County, Okla.-----	288-289	log of well of-----	80-82
Engle, N. Mex., materials penetrated at and near-----	232	Fortuna oil sand, features of, in the Cement oil field, Okla.-----	72
Estancia Valley, N. Mex., geology of-----	206-207	Fossils, occurrence of, in New Mexico-----	180, 181, 182
Esterito dome, N. Mex., description of-----	195-196	occurrence of, in Fort Berthold Indian Reservation, N. Dak.-----	116
record of boring in-----	198-199	Fruitland, N. Mex., record of deep well north of-----	250-251
F.		G.	
Fairview, N. Mex., geologic features south of-----	268-269	Gallup, N. Mex., record of city artesian well at-----	260-261
Farmington, N. Mex., record of deep well near-----	249-250	record of well southwest of-----	262
Farmington Oil & Gas Co., record of well bored by-----	249-250	Gallup-Zuni Basin, N. Mex., records of borings in-----	260-262
Fath, A. E., work of-----	110	stratigraphy of-----	259
Flora Vista, N. Mex., formations penetrated near-----	251	structure of-----	257-258, 259-260
Florida Mountains, N. Mex., features of-----	270	Gardner, J. R., acknowledgment to-----	196
Florida Plains, N. Mex., features of-----	270, 272	Gibson, N. Mex., formations penetrated at-----	262
Fort Berthold Indian Reservation, N. Dak., drainage of. 112-113		Girty, G. H., fossils determined by-----	180, 181
field work in-----	109-110, 110-111	Glaciation, effects of, in the Fort Berthold Indian Reservation, N. Dak.-----	114
lignite in, beds of-----	128-129	Gladstone Oil Co., analysis of oil produced by-----	75
beds of, plates showing-----	112, 142	log of well of-----	83-84
sections of, plates showing-----	132, 144, 154, 172	Glorieta Mesa, near La Cuesta, N. Mex., sandstone of, plate showing-----	188
distribution of. 126-127, 129-172		structure of-----	202
quantity of-----	125-126	Goldman, M. I., acknowledgment to-----	42
utilization of-----	127-128	Goodridge, Utah, oil wells at-----	246-247
value of-----	119, 125	Goodsight Mountains, N. Mex., features of-----	272
location of-----	109	Gordon, C. H., cited-----	268, 285
map of northern part of-----	In pocket	Grafton, Utah, locality favorable for drilling near-----	106-107
map of southern part of-----	In pocket	Greer formation. See Cyril gypsum member.	
map of southwestern part of-----	In pocket	Guadalupe County, N. Mex., record of boring in-----	204-205
physiography of-----	111-113	Guam, N. Mex., record of boring at-----	257
rolling upland in, plate showing-----	153	Gypsy Oil Co., record of hole bored by-----	198-199
settlement and industry in-----	113	H.	
stratigraphic sections in, plate showing-----	128	Hager, Lee, cited-----	291-292
stratigraphy of-----	113-117	Hancock, Eugene T., The New Salem lignite field, Morton County, N. Dak.-----	1-39
structure of-----	117-119	Hans Creek, N. Dak., sage-brush flat of, plate showing-----	153
Fort Union formation, bare buttes of, on Hans Creek, N. Dak., plate showing-----	140	Harrisburg dome, Utah, description of-----	99-101, 107
bluffs of, in North Dakota, plate showing-----	153	section of-----	92
features of, in North Dakota-----	5, 6, 8, 10-11	Heald, K. C., acknowledgment to-----	42
fossil log and stump in, plates showing-----	152	cited-----	56
log concretions in, plate showing-----	140	Heart River, N. Dak., valley of, plate showing-----	6
nature of, in the Fort Berthold Indian Reservation, N. Dak.-----	114-117		
origin of-----	118-119		

	Page.
Herald, Frank A., work of.....	110
Herald, Frank A., Bauer, Clyde Max., and, Lignite in the western part of the Fort Berthold Indian Reservation south of Missouri River, N. Dak.....	109-172
Hurricane fault scarp, Utah, sec- tion of.....	91

I.

Inscription Rock, N. Mex., plate showing.....	188
--	-----

J.

Jefferson County, Okla., southern part, earlier geologic work in.....	277-278
southern part, field work in.....	278
geography of special area in.....	277
Grogan anticline in.....	299, 301
prospecting in.....	300-302
"Red Beds" in.....	278-279
Red Creek anticline in.....	209, 301, 302
sand dunes in.....	285
Seay anticline in.....	299, 301-302
stratigraphy of.....	278-279
structural features in.....	297-300
map showing.....	284
Tertiary residual deposits in.....	284-285
Trinity sand in.....	283-284
unexposed rocks in.....	285-297
wells in, logs of.....	286-297
Wichita formation in.....	279-283
Jones, B. B., well, Jefferson County, Okla., log of.....	286-287
Jornada del Muerto, N. Mex., geo- logic features of.....	229-230
geologic map of.....	230
structure of.....	230, 231-232
Joyita Hills, N. Mex., geologic feat- ures of.....	239-240

K.

Keeche dome, Okla., description of.....	63-65
Keeche Hills, Okla., origin and form of.....	43
Keeche Oil & Gas Co., log of well of.....	82-83
Kenzin siding, N. Mex., record of deep well at.....	234
"Kingman dome," Utah, description of.....	103
Klowa area, Okla., structure of.....	68-69
structure of, map showing.....	In pocket.
topography of.....	43
Klondike Hills, N. Mex., features of.....	273
Knowlton, F. H., acknowledgment to.....	110
fossils determined by.....	6, 7, 11, 116

L.

	Page.
Lacasa area, Tex., Adame anticline in.....	310-311
Atkins anticline in.....	311-312
Bunger limestone in.....	308
gas well in.....	310, 312
geography and mapping of.....	303-304
Gonzales dome in.....	311
Gonzales limestone in.....	307-308
Home Creek limestone in.....	306-307
Hagaman terrace in.....	309
oil wells in.....	310, 313
Ranger limestone in.....	308
stratigraphy of.....	304-305
structure of.....	308-312
map showing.....	308
Veale anticline in.....	309-310
wells and borings in and near.....	313-314
plate showing records of.....	314
Laguna, N. Mex., materials pene- trated near.....	265
La Jara Peak, N. Mex., boring east of.....	266
Lake Valley, N. Mex., geologic fea- tures north of.....	268-269
Lance formation, features of, in North Dakota.....	5, 6, 7, 9
Landslides on Missouri River, N. Dak., features of.....	162- 163, 166
La Plata group, nature and dis- tribution of, in New Mexico.....	184
Lee, W. T., cited.....	191
Lemitar Mountains, N. Mex., geo- logic features of.....	240-241
Lenark, N. Mex., record of deep well at.....	233
Lignite, analyses of.....	17-20, 120-122
burning of beds of.....	117
heating power of.....	123-124
importance of, in North Da- kota.....	109
in Fort Berthold Indian Reser- vation, N. Dak., nature and distribution of.....	119-172
in New Salem field, N. Dak., na- ture and occurrence of.....	12-39
sections showing features of.....	14
Lincoln, N. Mex., anticline west of.....	209-210
Lincoln County, N. Mex., basin in.....	209
Little Hatchet Mountains, N. Mex., features of.....	274-275
Little Missouri River, "breaks" of, near Hans Creek, N. Dak., plate showing.....	112
features of, in Fort Berthold Indian Reservation, N. Dak.....	112-113
intrenchment of.....	111

	Page.		Page.
Log, fossil, standing in the Fort Union formation, N. Dak., plate showing-----	152	Negra, N. Mex., formations penetrated at-----	205
Lordsburg, N. Mex., materials penetrated near-----	275	New Mexico, conditions favorable and unfavorable to oil in-----	178-175
Lucy, N. Mex., formations penetrated at-----	205	central eastern, records of borings in-----	197-200
M.		stratigraphy of-----	195
McGee boring, Quay County, N. Mex., log of-----	199-200	structure of-----	194, 195-197
McKinley Oil & Drilling Co., log of well of-----	84-85	Colfax County, dome in-----	189-190
Magdalena group, base of, plate showing-----	236	east-central plateau region, records of borings in-----	203-205
nature and distribution of, in N. Mex.-----	179-180	stratigraphy of-----	201-202
upturned beds of, plate showing-----	236	structure of-----	202
Malpais siding, N. Mex., materials penetrated at-----	284	Luna County, ridges in northwest corner of-----	274
Mancos shale, features of, in New Mexico-----	185	map of-----	174
Mansano group, nature and distribution of, in New Mexico-----	181-182	northeastern, dome in-----	189-190
Mansano Mountains, N. Mex., geologic map of-----	218	formations in-----	176
structure of-----	217-218	records of borings in-----	192-194
Marion Oil & Gas Co., log of well of, in Jefferson County, Okla.-----	290-291	stratigraphy of-----	190-192
Matson, G. C., acknowledgment to-----	196, 198	structure of-----	192
Mesa del Yeso, N. Mex., plate showing-----	237	northwestern, formations in-----	177-178
Mesaverde group, subdivisions and distribution of, in New Mexico-----	185-186	older Paleozoic rocks in, complete exposure of-----	179
Missouri River, features of, in Fort Berthold Indian Reservation, N. Dak.-----	112	sedimentary rocks in, general succession of-----	175-179
from upper margin of the badlands, in North Dakota, plate showing-----	114	southern, formations in-----	178-179
Moccasin Creek, N. Dak., valley of, plate showing-----	114	southwestern, geologic features of-----	269-275
Mohave County, Ariz., possibilities of oil in-----	104-105	Union County, dome in-----	189-190
Moore, Raymond C., work of-----	3	west-central volcanic area, geologic features of-----	267
Morrison formation, nature and distribution of, in New Mexico-----	184-185	New Salem lignite field, N. Dak., access to-----	4
Mount Riley siding, N. Mex., materials penetrated at-----	283	early explorations near-----	3-4
N.		field work on-----	1, 2, 3
Nacimiento uplift, N. Mex., stratigraphy of-----	241	geography of-----	4-5
structure of-----	241, 242	geology of-----	5-12
Navajo Church, N. Mex., sandstones at, plate showing-----	189	map showing-----	38
Navajo sandstone, at Atarque, N. Mex., plate showing-----	196	lignite in, chemical properties of-----	15-17, 20, 21
in New Mexico, nature and distribution of-----	184	exposures of-----	25-39
		heating value of-----	21-23
		mining of-----	23-25
		origin and distribution of-----	12-14
		physical properties of-----	14-15
		location of-----	1, 2
		towns in-----	28, 31, 34, 36, 37
		upland in vicinity of, plate showing-----	6
		Noria, N. Mex., materials penetrated at-----	282-283
		North Chaves siding, N. Mex., record of well at-----	255-257
		North Garcia siding, N. Mex., materials penetrated at-----	264-265
		O.	
		Office of Indian Affairs, cooperation by-----	42
		Oil. See Petroleum.	
		Oklahoma, geologic map of, showing oil and gas fields-----	42
		index map of-----	278

	Page.		Page.
Orchard Park, N. Mex., formations penetrated near-----	216	Quemado, N. Mex., boring northeast of-----	267
Orogrande, N. Mex., materials penetrated at-----	228		
Oscura anticline, N. Mex., structural features of-----	239	R.	
Oscuro, N. Mex., materials penetrated at-----	228	Baton coal field, N. Mex., formations present in-----	191-192
P.		likelihood of oil and gas in-----	192
Parks, E. M., work of-----	110	"Red Beds," distance of oil sands below, in Texas and Oklahoma-----	295-296
Pastura, N. Mex., rocks penetrated by well at-----	199	Improbability of oil in-----	187-188
Pecos River valley in Chaves and Eddy counties, N. Mex., oil in-----	211-212	origin of-----	58
records of borings in-----	212-216	Permian, nature and distribution of, in New Mexico-----	181-182
stratigraphy of-----	210-211	Triassic, nature of, in New Mexico-----	182-183
structure of-----	211	Reeside, John B., Jr., acknowledgments to-----	250, 251
Pederal Siding, N. Mex., formations penetrated at-----	205	Bassler, Harvey, and, Oil prospects in Washington County, Utah-----	87-107
Peloncillo Mountains, N. Mex., features of-----	275	Reeves, Frank, Geology of the Cement oil field, Caddo County, Okla-----	41-85
Petroleum, accumulation of, relation of structure to-----	61-62	Rio Grande valley, in central New Mexico, geologic features of-----	220-221
formations likely or unlikely to contain, in New Mexico-----	187-189	in northern New Mexico, formations in-----	217
occurrence of, in the Pecos River valley, N. Mex.-----	211-212	in southern New Mexico, materials penetrated in-----	232-234
Picacho, N. Mex., dome near-----	209	Rio Puerco station, N. Mex., materials penetrated at-----	264
formations penetrated by boring near-----	210	Rio Salado valley, N. Mex., map showing structure of-----	266
Pierce, O. H., work of-----	110	Robinson, Heath M., Geologic structure and oil and gas prospects of a part of Jefferson County, Okla-----	277-302
Pilot Knob, N. Mex., plate showing-----	228	Rocky Mountains, prolongation of, in New Mexico-----	202
Pintada Canyon, N. Mex., dome in-----	197	structure of, in New Mexico-----	200-201
Plains of San Agustin, N. Mex., geologic features of-----	268	Ross, Clarence S., The Lacasa area, Ranger district, north-central Texas-----	303-314
wells bored in-----	268	Roswell, N. Mex., records of borings near-----	212-215
Platt well, near Dayton, N. Mex., gas from-----	211	Roundy, P. V., acknowledgment to-----	42
Plummer, Frederick B., cited-----	306	cited-----	293
Prairie Spring anticline, N. Mex., structural features of-----	238	Ryan, Jefferson County, Okla., anticline east of-----	299-300, 301, 302
Producers Oil Co., log of well of, near Petrolia, Tex-----	292-294	Ryan City Oil Co., log of well of, in Jefferson County, Okla-----	291
Prosperity oil sand, features of, in the Cement oil field, Okla-----	72		
Pueblo Bonito School, McKinley County, N. Mex., materials penetrated near-----	251	S.	
Purgatoire River, south fork of, in N. Mex., geologic section on-----	191	Sacramento Cuesta, N. Mex., formations penetrated by boring in-----	210
Pyramid Mountains, N. Mex., features of-----	275	stratigraphy of-----	207-208
Pyramid Rock, N. Mex., plate showing-----	254	structure of-----	209-210
Q.			
Quaternary deposits, nature and distribution of, in New Mexico-----	187		

	Page.		Page.
Sacramento Mountains, N. Mex., west front of, plate showing.....	197	Steiger, George, analyses by.....	74
Sage-brush flat of Hans Creek, N. Dak., plate showing.....	153	Stinchecum, C. V., acknowledgment to.....	42
St. George, Utah, anticlines near.....	103-104	Strauss, N. Mex., materials penetrated at.....	232
composite section for region near.....	92-93	Stump, fossil, in the Fort Union formation, plate showing.....	152
San Agustin plains, N. Mex., geologic features of.....	268	Suwanee, N. Mex., materials penetrated near.....	265
wells bored in.....	268	Swanker, Sidney, work of.....	8
San Andres Mountains, N. Mex., geologic features of.....	229		
Sandia Mountains, N. Mex., geologic map of.....	218	T.	
structure of.....	217-218	Tannehill well, N. Mex., record of.....	215
west front of, plate showing.....	218	Taylor coal basin, N. Mex., geologic features of.....	238
San Ignacio, N. Mex., dome near, plate showing.....	197	Tertiary deposits, nature and distribution of in New Mexico.....	186-187
San Juan Basin, N. Mex., oil and gas in.....	246-247	Texas, north-central, Pennsylvanian formations in.....	285
records of borings in.....	249-253	Tljeran, N. Mex., anticline north of.....	218
structure of.....	245-246, 247-248	Tinnie, N. Mex., dome near.....	209
San Juan Basin Oil & Gas Co., records of deep wells bored by.....	250-251	Toddlito formation, nature and distribution of in New Mexico.....	184
San Luis Range, N. Mex., features of.....	275	Tohachi, N. Mex., record of well southeast of.....	252-253
Seay, Oscar, well No. 1, Jefferson County, Okla., log of.....	287-288, 294	Toltec Co., records of borings made by.....	203-204, 212-213
Seven Lakes, N. Mex., formations penetrated near.....	251	Tres Hermanas Mountains, N. Mex., features of.....	272
Shea, Edward F., work of.....	41	Tularosa Basin, N. Mex., geologic map of.....	224
Sierra de los Pinos, N. Mex., geologic map of.....	218	materials penetrated in.....	227-229
structure of.....	217-218	stratigraphy of.....	223-226
Sierra Lucero, N. Mex., sections across, plate showing.....	262	structure of.....	223, 226-227
Sierrita Mesa, N. Mex., plate showing.....	237		
Sims, N. Dak., syncline at.....	12	U.	
Smith's Mesa, Utah, section of.....	90-91	United Oil Co., record of boring of, in Union County, N. Mex.....	193-194
Socorro County, N. Mex., geologic maps of parts of.....	234, 262		
eastern part, structure of.....	234-241	V.	
north-central part, stratigraphy of.....	265-266	Valencia County, N. Mex., geologic map of part of.....	262
structure of.....	265, 266	east-central part, records of borings in.....	264-265
Socorro Mountains, N. Mex., geologic features of.....	240-241	stratigraphy of.....	263, 264
Southern Pacific Co., records of wells bored by.....	232-234	structure of.....	262, 264
Southspring Ranch & Cattle Co., record of boring by.....	214-215	Valle del Ojo de la Parida, N. Mex., features of.....	237-238
Springs in Fort Berthold Indian Reservation, N. Dak., features of.....	113, 131	Valle Grande area, N. Mex., features of.....	245
Squaw Creek, N. Dak., view on.....	161	Victorio Mountains, N. Mex., features of.....	273
Staked Plains region in N. Mex., boring in.....	216	Virgin anticline, Utah, description of.....	99-103
formations in.....	216	Virgin City, Utah, localities favorable for drilling near.....	106
Stanton, T. W., acknowledgment to.....	110	oil wells near.....	93-95, 96
fossils determined by.....	6, 7, 10, 116	Virgin River, section in narrows of, Ariz.....	92-93
State wells, Torrance County, N. Mex., records of.....	204		

11

12

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